NASA/CR—2003-212380

TFaNS—Tone Fan Noise Design/ Prediction System

Users' Manual, TFaNS Version 1.5

David A. Topol
United Technologies Corporation, Pratt & Whitney, East Hartford, Connecticut

June 2003

The NASA STI Program Office . . . in Profile

Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA Scientific and Technical Information (STI) Program Office plays a key part in helping NASA maintain this important role.

The NASA STI Program Office is operated by Langley Research Center, the Lead Center for NASA's scientific and technical information. The NASA STI Program Office provides access to the NASA STI Database, the largest collection of aeronautical and space science STI in the world. The Program Office is also NASA's institutional mechanism for disseminating the results of its research and development activities. These results are published by NASA in the NASA STI Report Series, which includes the following report types:

- TECHNICAL PUBLICATION. Reports of completed research or a major significant phase of research that present the results of NASA programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA's counterpart of peer-reviewed formal professional papers but has less stringent limitations on manuscript length and extent of graphic presentations.

- TECHNICAL MEMORANDUM. Scientific and technical findings that are preliminary or of specialized interest, e.g., quick release reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.

- CONTRACTOR REPORT. Scientific and technical findings by NASA-sponsored contractors and grantees.

- CONFERENCE PUBLICATION. Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or cosponsored by NASA.

- SPECIAL PUBLICATION. Scientific, technical, or historical information from NASA programs, projects, and missions, often concerned with subjects having substantial public interest.

- TECHNICAL TRANSLATION. English-language translations of foreign scientific and technical material pertinent to NASA's mission.

Specialized services that complement the STI Program Office's diverse offerings include creating custom thesauri, building customized databases, organizing and publishing research results . . . even providing videos.

For more information about the NASA STI Program Office, see the following:

- Access the NASA STI Program Home Page at ***http://www.sti.nasa.gov***

- E-mail your question via the Internet to help@sti.nasa.gov

- Fax your question to the NASA Access Help Desk at 301–621–0134

- Telephone the NASA Access Help Desk at 301–621–0390

- Write to:
  NASA Access Help Desk
  NASA Center for AeroSpace Information
  7121 Standard Drive
  Hanover, MD 21076

NASA/CR—2003-212380

TFaNS—Tone Fan Noise Design/ Prediction System

Users' Manual, TFaNS Version 1.5

David A. Topol
United Technologies Corporation, Pratt & Whitney, East Hartford, Connecticut

Prepared under Contract NAS3–27727, Task 13

National Aeronautics and
Space Administration

Glenn Research Center

June 2003

Acknowledgments

This report was prepared under NASA Contract NAS3–27727, Task 13 for the NASA Glenn Research Center. The NASA Task Manager was Dennis Huff. Pratt & Whitney's Task Manager was Wesley Lord for Task 13. Parts of the inlet and aft radiation code's documentation were obtained from W. Eversman's code comment statements. The author gratefully acknowledges D.B. Hanson, B. Morin, and W. Eversman for their help and useful suggestions, which helped make the improvement of this system possible.

Note that at the time of research, the NASA Lewis Research Center was undergoing a name change to the NASA John H. Glenn Research Center at Lewis Field. Both names may appear in this report.

Available from

NASA Center for Aerospace Information
7121 Standard Drive
Hanover, MD 21076

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22100

Available electronically at http://gltrs.grc.nasa.gov

TABLE OF CONTENTS

TFaNS—Tone Fan Noise Design/Prediction System

Users' Manual, TFaNS Version 1.5

David A. Topol
United Technologies Corporation
Pratt & Whitney
East Hartford, Connecticut 06108

SUMMARY

TFaNS is the Tone Fan Noise Design/Prediction System developed by Pratt & Whitney under contract to NASA Glenn. The purpose of this system is to predict tone noise emanating from a fan stage including the effects of reflection and transmission by the rotor and stator and by the duct inlet and nozzle. The user's manual for the first version of this design system may be found in Reference 1. Several improvements have been made to TFaNS. This user's manual shows how to run this new system.

The underlying concept for the system was presented in Reference 2 with application to cascades in 2−dimensional channels. TFaNS extends this to annular geometry with duct terminations and radiation to the far−field via the following scheme: "Acoustic elements" (e.g. the inlet, the rotor, the stator, and the nozzle) are first analyzed in isolation to determine their modal reflection and transmission coefficients (including frequency scattering in the case of the rotor). Then the elements are coupled as a linear system via the duct eigenmodes at "interface planes" separating the elements. The linear system is solved to find a "state vector" of mode amplitudes at the interface planes. The "state vector" then is used to compute upstream and downstream modal sound powers and the sound pressure directivities in the outside field.

TFaNS consists of:

- The codes that compute the acoustic properties (reflection and transmission coefficients) of the various elements and writes them to Acoustic Properties Files,
- CUP3D: Fan Noise Coupling Code that reads these files, solves the coupling equations, and outputs the desired noise predictions,
- AWAKEN: CFD/Measured Wake Postprocessor which reformats CFD wake predictions and/or measured wake data so they can be used by the system to predict noise.

Acoustic properties can be computed from a variety of codes other than those presently in TFaNS. For example, rotor and stator reflection and transmission are currently being computed from a classical, uniform axial flow model with solid body swirl. However, more sophisticated codes (e.g. linearized Euler codes) are anticipated for future application. CUP3D has been written in a general form so that acoustic properties from a variety of codes can be handled. To accomplish this, a standard file format for acoustic properties has been developed and must be followed.

This document provides information for potential users of TFaNS. The following sections provide the background necessary to run the various codes in TFaNS. The first part of the discussion will include the organization of the TFaNS codes. Then instructions for how to run the CUP3D Fan Noise Coupling Code will be given. Next, user information about the SOURCE3D rotor wake/stator interaction code, the Eversman Inlet Radiation code and the Eversman Aft Radiation code will be presented. Finally, AWAKEN CFD/Measured Wake Postprocessor instructions will be presented.

Technical documentation of the TFaNS codes is given in References 3 through 9. Evaluation of the previous TFaNS system codes (TFaNS Version 1.4) may be found in Reference 10.

1. INTRODUCTION

The TFaNS coupling and noise prediction scheme is explained conceptually with reference to Figure 1.

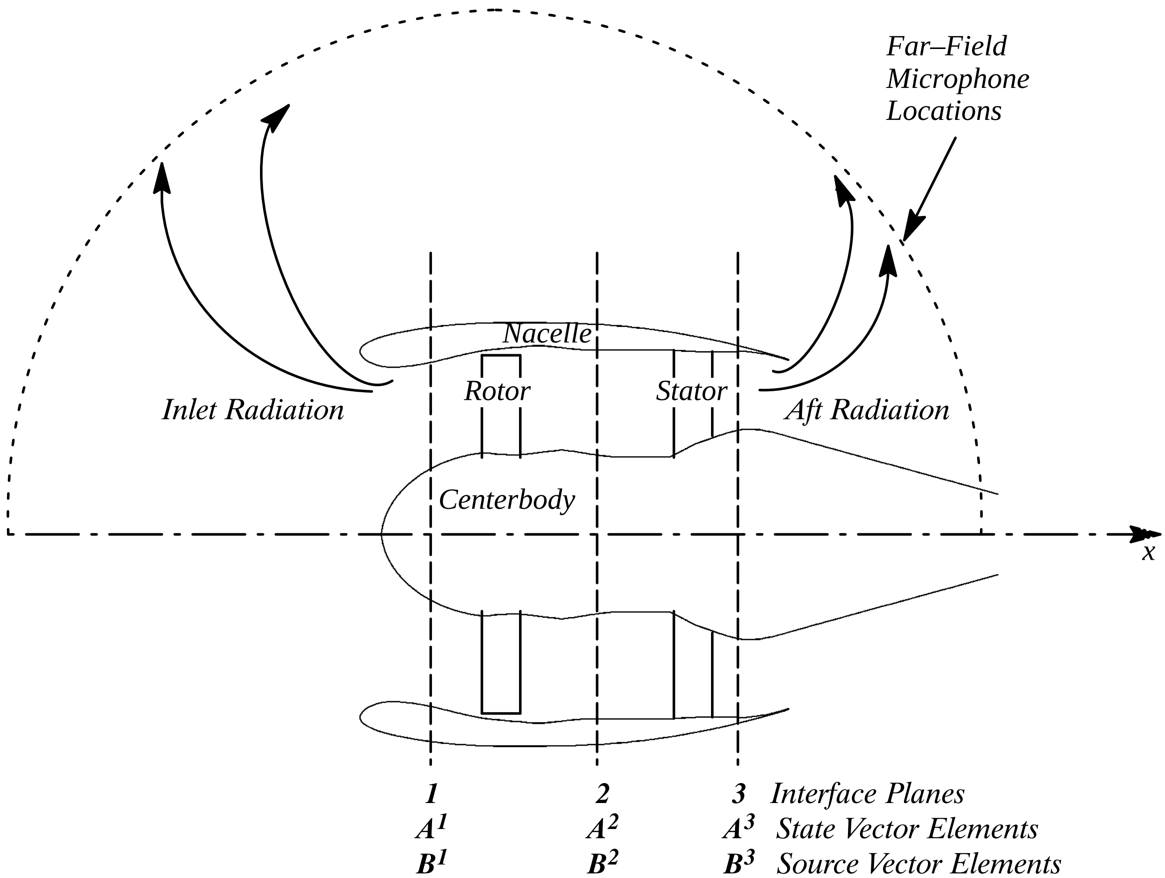


Figure 1: TFaNS Coupling and Noise Prediction Scheme

The fan stage is divided by three interface planes into four acoustic elements (inlet, rotor, stator, and nozzle). State vector, $\boldsymbol{A}$, is in three sections, $\boldsymbol{A^1}$, $\boldsymbol{A^2}$, and $\boldsymbol{A^3}$, whose elements are the modal amplitudes (see Reference 3 for more information). Source vector, $\boldsymbol{B}$, has the same structure. $\boldsymbol{B}$ is prescribed (corresponding, for example, to the output of a stator due to rotor wake input in an uncoupled environment) and $\boldsymbol{A}$ is to be found as a function of $\boldsymbol{B}$ by solving the linear system equations.

Coupling of the elements at the interface planes is specified in terms of the scattering matrix, $\boldsymbol{S}$, which is built up from modal reflection and transmission coefficients. In condensed form, the system equations are represented by

$$\boldsymbol{A} = \boldsymbol{SA} + \boldsymbol{B} \tag{1}$$

which is to say that the state vector elements are the sum of the parts from scattering, $\boldsymbol{SA}$, and directly from the source, $\boldsymbol{B}$. These equations are solved formally by

$$\boldsymbol{A} = (\boldsymbol{1} - \boldsymbol{S})^{-1}\boldsymbol{B} \tag{2}$$

Two major forms of noise output are computed from the state vector:

- Upstream and downstream propagating sound power level are computed from $\boldsymbol{A}$ on a mode−by−mode basis. Power is calculated just upstream and just downstream of the noise source (defined in Figure 1 by interface plane 1 upstream, and interface plane 3 downstream).
- Outside far−field directivity is computed from the elements of $\boldsymbol{A}$. In this case, far−field directivity shapes are computed by the radiation codes with unit amplitude input and stored as part of the acoustic properties files. These directivities are then multiplied by $\boldsymbol{A}$ to get the far−field sound pressure level directivity.

TFaNS (Version 1.5) consists of the following computer codes:

- CUP3D: Fan Noise Coupling Code Version 2.1 (Reference 3)
- SOURCE3D: Rotor Wake/Stator Interaction Code Version 2.6 (Reference 4)
- Eversman Inlet Radiation code Version 4.0 (References 5 to 9)
- Eversman Aft Radiation code Version 4.0 (References 6 to 9)
- AWAKEN: CFD/Measured Wake Postprocessor Version 1.1

With the exception of CUP3D, all of the above codes were updated from TFaNS Version 1.4 (Reference 1). The changes from Version 1.4 to Version 1.5 are as follows:

- SOURCE3D has a new transmission loss calculation for modes scattering into themselves using a method developed by Philpot (See Reference 11).
- The inlet and aft radiation codes use infinite envelope elements in the far−field (See Reference 9).
- AWAKEN uses a new Acoustic Wake/Turbulence File format (See Section 8.2.2).

The following sections present the organization of TFaNS and the general procedure for running TFaNS. After that each code's user manual will be presented in the order given above. Appendix I presents information regarding the TFaNS subdirectory structure, for those who need this information.

2. GENERAL ORGANIZATION OF TFaNS

The organization of TFaNS is illustrated in Figure 2. This figure identifies the codes which comprise the system and how they interact with each other.

The central portion of the system is the CUP3D Fan Noise Coupling Code. This code reads acoustic properties files which contain scattering (transmission and reflection) coefficients from other codes along with far−field directivity shapes and source vector information (e.g. noise from rotor wake/stator interaction). This information is used to form a system of linear equations which permit acoustic elements to reflect and transmit to each other. A system file is also input which determines the organization of the acoustic elements. Output from this code includes far−field directivities along with inlet and aft power levels.

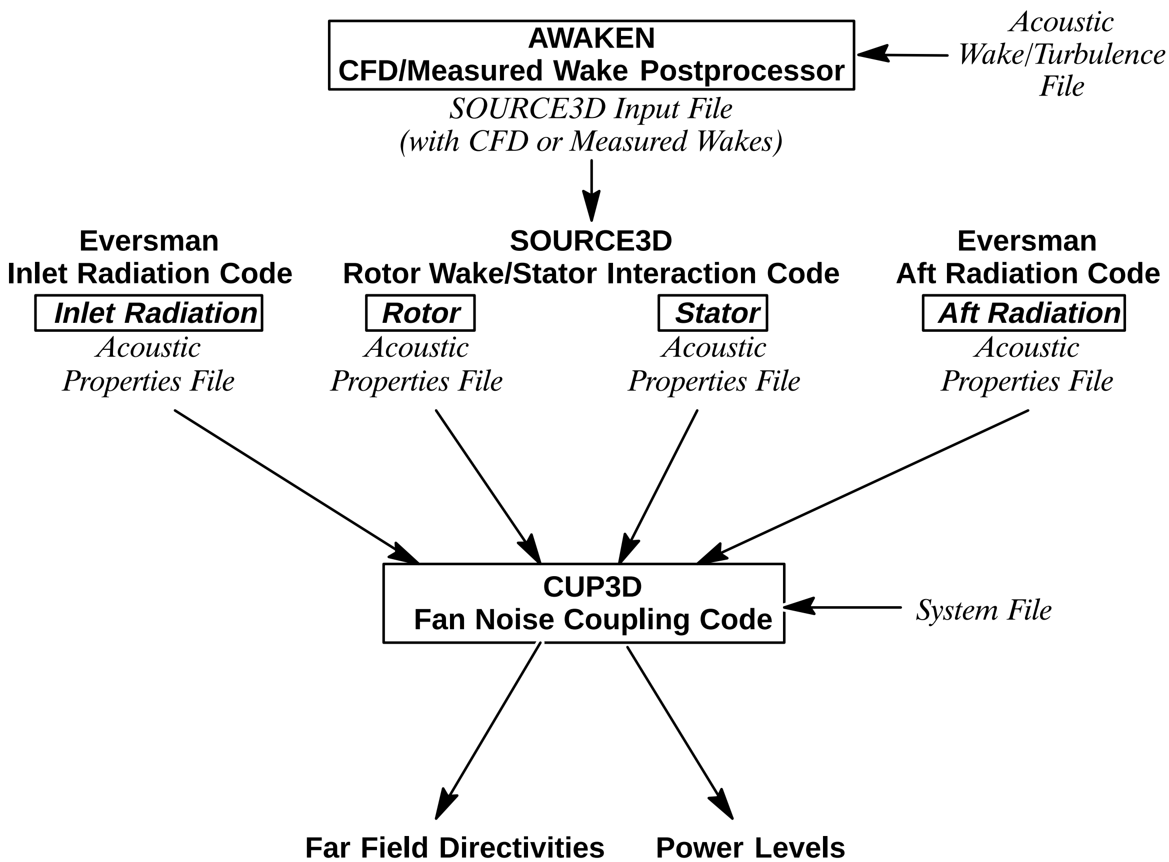


Figure 2: Organization of TFaNS Version 1.5

The SOURCE3D Rotor Wake/Stator Interaction Code is a significantly extended and improved version of the V072 Rotor Wake/Stator Interaction Code (Reference 12, 13 and 14). It has two functions within TFaNS: firstly, it calculates tone noise from a rotor wake/FEGV interaction and, secondly, it determines the scattering coefficients for the rotor and stator then outputs them to rotor and stator acoustic properties files (Figure 2) for use by CUP3D. This code can either use its own internal semi−empirical wake model, or it can use CFD or measured wakes processed through the AWAKEN CFD/Measured Wake Postprocessor. The code's input can be set up to run SOURCE3D for one or more cases where a case is defined as a particular engine or rig geometry running at a given operating condition.

The AWAKEN CFD/Measured Wake Postprocessor creates a SOURCE3D input file which contains upwash wake harmonic amplitudes calculated from CFD predictions or measured velocity data. CFD or measured velocity information is obtained from the Acoustic Wake/Turbulence File which is generated either by a CFD code (or postprocessor) or during an engine/rig test program. This code can be run for multiple cases to generate multiple case SOURCE3D input files.

The Eversman inlet and aft radiation codes must be run if far−field directivities are required. These codes comprise three "modules". The first module creates a finite element mesh for the calculation. The second module calculates the potential steady flow using a method which separates the problem into three separate potential flow problems. This makes it possible to run the potential steady flow module once for a given nacelle geometry without knowledge of the duct flow conditions. Finally a radiation module, modified to interface with TFaNS, superimposes the potential steady flow solutions for a given set of duct flow conditions and calculates the far field radiation and scattering coefficients for a specified number of blade passing frequency (BPF) harmonics on a mode−by−mode basis.

These codes are each designed so that the user creates one mesh which is used to run multiple harmonics of blade passing frequency (BPF). The steady flow calculation is then run once for a given computational mesh. Then special versions of the radiation modules ("inlrad3d" and "aftrad3d", "aftrad3d10") are run to calculate scattering coefficients and far−field directivities for CUP3D. Acoustic properties files are output. These codes can only be run one case at a time and must be used with one case runs from the SOURCE3D code. It is anticipated that future versions of the radiation codes will permit multiple cases to be run.

3. PROCEDURE FOR RUNNING TFaNS

The code executables required to run TFaNS are:

Executable	Computer Code
cup3d	Fan Noise Coupling Code
source3d	Rotor wake/stator interaction code
inlmesh	Inlet Radiation Code mesh calculation
inlflow	Inlet Radiation Code Potential flow calculation
inlrad3d	Inlet Radiation Code Radiation Module for TFaNS
aftmesh	Aft Radiation Code mesh calculation
aftflow	Aft Radiation Code Potential flow calculation
aftflow10	Aft Radiation Code Potential flow calculation (Sun SPARC Capable)
aftrad3d	Aft Radiation Code Radiation Module for TFaNS
aftrad3d10	Aft Radiation Code Radiation Module for TFaNS (Sun SPARC Capable)
awaken	CFD/Measured Wake Postprocessor

To run the system:

If CFD or measured wakes are being used:

1. Run the AWAKEN code using the instructions in Section 8.
   This will create a SOURCE3D input file.

Then:

2. Run the SOURCE3D code using the instructions in Section 5.

If inlet coupling or inlet radiation is required:

3. Run the inlet radiation code using the instructions in Section 6.

    a. Create an inlet mesh using “inlmesh”

    b. Create inlet steady flow files using “inlflow”

    c. Calculate inlet radiation using “inlrad3d”

If nozzle coupling or aft radiation is required:

4. Run the aft radiation code using the instructions in Section 7.

    a. Create an aft mesh using “aftmesh”

b. Create nozzle (aft) steady flow files using “aftflow” (or “aftflow10” on Sun Systems)

c. Calculate aft radiation using “aftrad3d” (or “aftrad3d10” on Sun Systems)

The following Acoustic Properties Files are created:

Acoustic Properties File	From Computer Code
inlrad	Inlet Radiation
input_filename.s3drot	Rotor file from SOURCE3D
input_filename.s3dsta	Stator file from SOURCE3D
aftrad	Aft Radiation Code

5. Create a CUP3D System File (see Section 4.) to couple the above acoustic elements.

6. Run CUP3D using the instructions in Section 4.

7. Far−field directivities and/or power levels will be output to files suitable for plotting.

The remainder of this document contains the user manuals for the five codes in TFaNS: CUP3D, SOURCE3D, the Eversman inlet and aft radiation codes and AWAKEN. Each manual will describe the input files required for running and the output files created. A sample input file is shown for each code. Methods for running will also be discussed. Note that this documentation assumes that a path in the computer subdirectory system has been created to access all TFaNS code executables given above.

4. CUP3D FAN NOISE COUPLING CODE VERSION 2.1

4.1 GENERAL ORGANIZATION OF CUP3D

The CUP3D Fan Noise Coupling Code is the final link in the TFaNS Tone Fan Noise design/prediction System. CUP3D permits developers of isolated blade row and radiation codes to use non−reflecting boundary conditions. CUP3D then uses output files from these isolated elements to “couple” the elements thus accounting for reflection and transmission of acoustic and vorticity waves throughout the system.

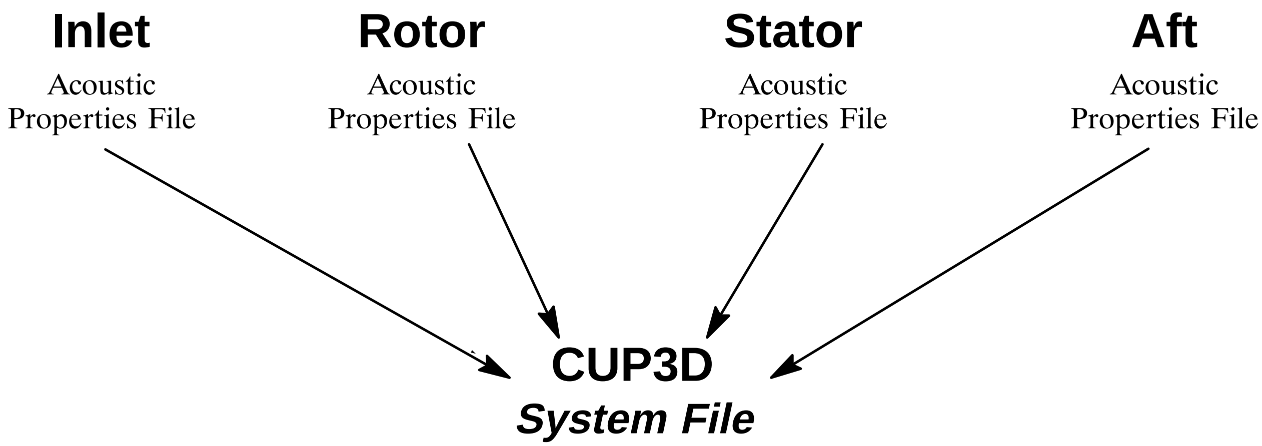


Figure 3: CUP3D File Organization

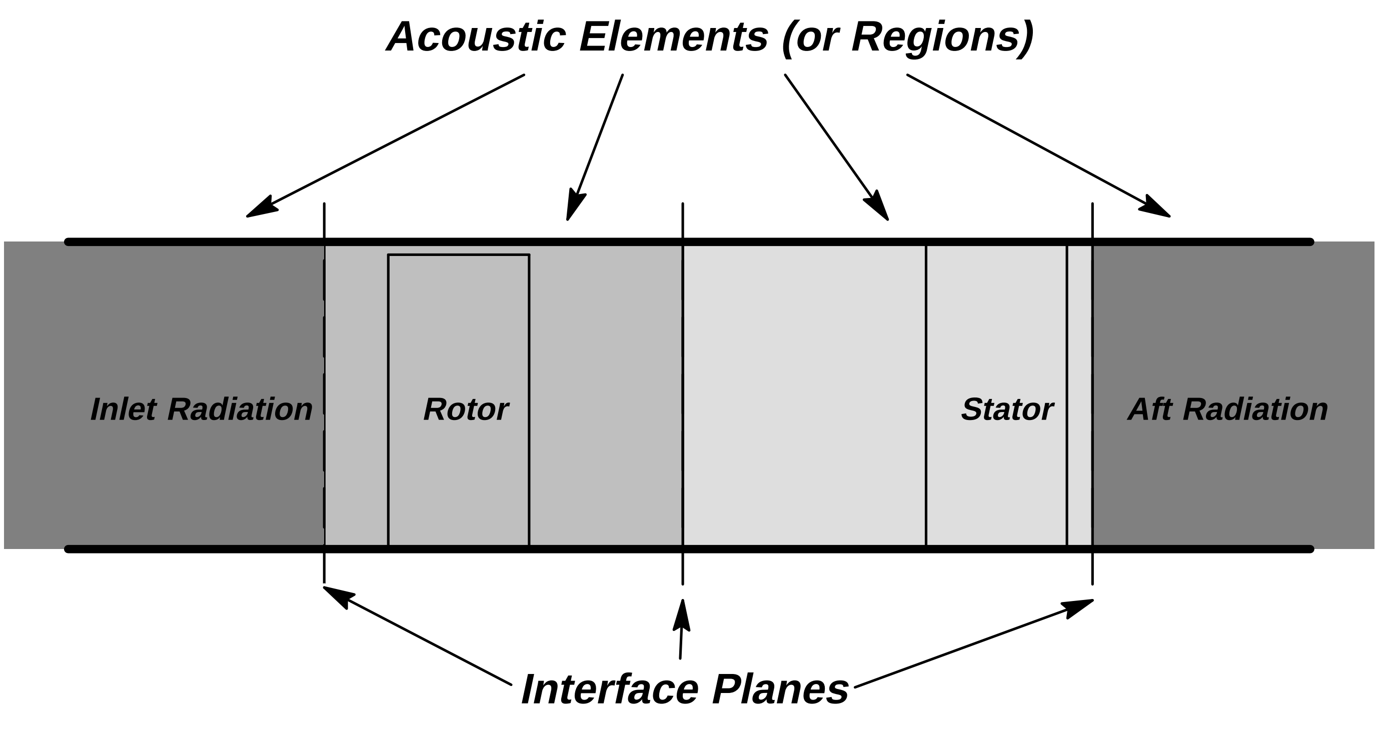


Figure 4: CUP3D Geometry and Terminology

Figure 3 is a block diagram showing the files required by CUP3D. First, codes such as an inlet radiation code, rotor code, stator code, and aft radiation code are run. These codes create Acoustic Properties Files which contain all the acoustic information about an acoustic element. The information may include geometry and performance, harmonic and mode numbers, scattering coefficients, source vector coefficients and far–field directivity shapes. These acoustic properties files and a user generated System File are then input into CUP3D. The System File contains information on how the various acoustic elements will be organized to form the total acoustic system. An example of an acoustic system is shown in Figure 4.

Information about the terminology and geometry used by CUP3D is given in Figure 4. The present system can be organized with up to four acoustic elements (or regions). These elements are classified by any of four types: inlet radiation, rotor, stator, and aft radiation. The number and types of elements used may vary from case to case. However, if radiation elements are not used, they must be replaced by non–reflecting regions which act to propagate the noise away from the system. Output from CUP3D includes inlet and aft mode and total power levels and far–field directivities.

Each acoustic element is bounded by interface planes. Rotor and stator acoustic elements are bounded by two interface planes. Inlet and aft radiation acoustic elements are bounded by one interface plane and the far–field. These boundaries are non–reflecting and permit waves to be sent into an acoustic element one at a time. Reflection and transmission scattering coefficients can then be calculated.

Additional technical information about this code may be found in Reference 3. The next sections will present the input file structure, output file structure and method to run the code.

4.2 INPUT FILE STRUCTURE

4.2.1 General information

Two types of files are input into CUP3D:

- CUP3D System File is created by the user and is used to specify the elements of the engine geometry to be included in the prediction.
- Acoustic Properties File is created by other codes (e.g. inlet radiation). It contains header information, scattering matrix information, source vector information and far−field directivities for the acoustic element being predicted (e.g. inlet radiation, rotor, stator, aft radiation).

The system uses the following terminology (see Figure 3 and Figure 4):

- An acoustic element (or region) refers to a part of the system with acoustic properties such as a rotor, stator, inlet radiation or aft radiation. An Acoustic Properties File must be created for any acoustic element with acoustic reflection properties. An Acoustic Properties File is not needed for a non−reflecting region.
- An interface plane is the plane where two acoustic elements meet.
- Scattering coefficients are the reflection and transmission coefficients for a particular region (see Reference 3).
- The Source Vector contains the pressure or vorticity wave mode amplitudes resulting from a prescribed outside influence such as a rotor wake interacting with a stator vane.

4.2.2 CUP3D System File

The user creates a CUP3D system file to form the engine geometry being predicted. An example of an engine geometry is shown in Figure 5. Note that the geometry in this figure includes an inlet, rotor, stator, nozzle. In addition, the figure shows a compressor inlet guide vane (IGV); it is shown shaded because, while the IGV is commonly found in an engine, it is not presently considered by CUP3D. Also note that this is not the only geometry that a user can run. Other geometries may also be run by omitting one of these elements or rearranging the elements.

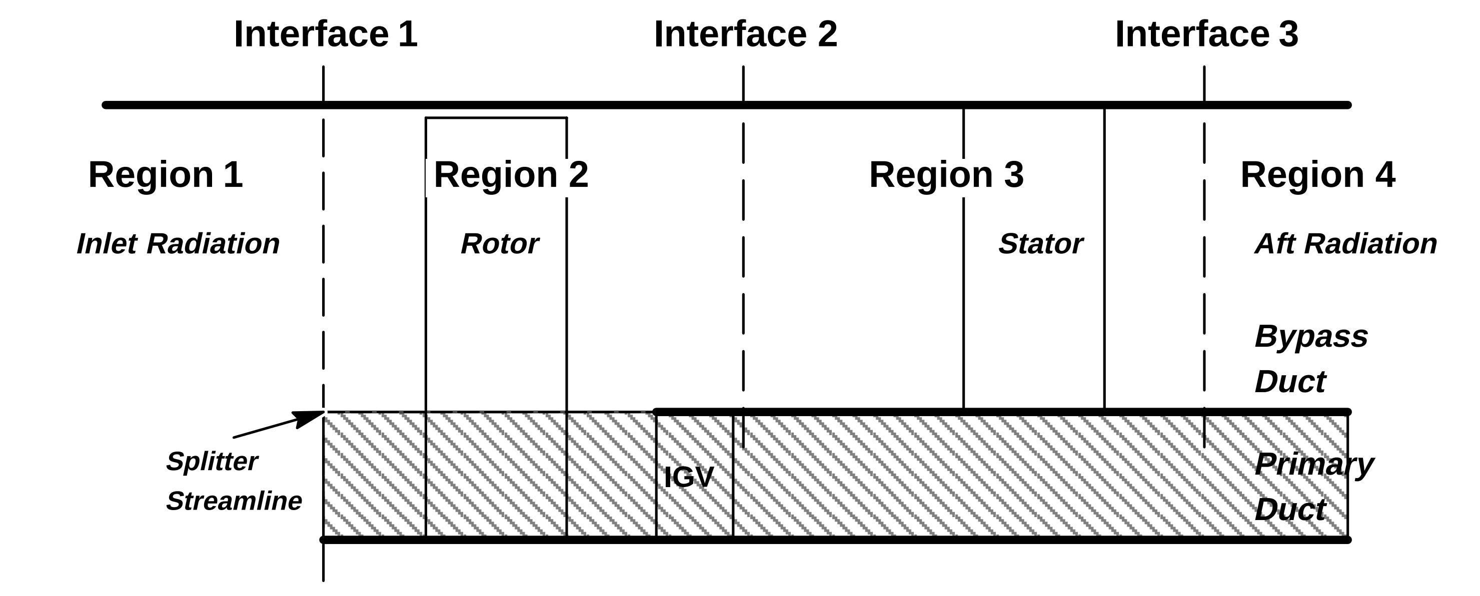


Figure 5: CUP3D Region and Interface Plane Designations

4.2.2.1 System File Format

The input data file structure has distinct blocks of input data referred to as cards. Each card begins on a new line. With the exception of CONTRLTIT, input is in a free format as illustrated in the examples. The title cards just above each numerical input line are designed to assist the user in identifying what is in the file.

Card 1: CONTRLTIT: User input title for this run: FORMAT(A80)

Card 2: Alpha numeric characters explaining what is in card 3.

Card 3:

- NHARM: Number of Harmonics Being Run (needs to be less than or equal to the value of NHT in the Acoustic Properties Files for all acoustic elements. See Section 4.2.3.1, card 4).
- NCASER: Number of Cases being run (needs to less than or equal to the value of NCASE in the Acoustic Properties Files for all acoustic elements. See Section 4.2.3.1, card 1).
- DFAN: Fan tip diameter (inches), fan leading edge (is the same as DDUCT in SOURCE3D, see Section 5.2.6, and DFAN in the inlet and aft radiation codes unless engine is being scaled for size)
- PINF: Static Pressure (psia) in the far−field (far from the nacelle) (normally 14.696 psi)
- TINF: Static Temperature (^{0}R) in the far−field (far from the nacelle) (normally standard acoustic day temperature 536.67^{0}R/77^{0}F)

Card 4: Alpha numeric characters explaining what is in cards 5 through the end.

Card 5: Organization of acoustic elements. List the information for each acoustic element on a separate line.

- IREGION: Region Number of the acoustic element (start with 1, end with any number up to 4)
- FILENAM: File name of the Acoustic Properties File for the acoustic element. Enclose this file name in single quotes as shown in the examples in Section 4.2.2.3. The first character in these file names must be a letter. Maximum file name length: 20 characters.

  If region is non−reflecting, then use file name 'NONREFL'. The code will then recognize that there is no Acoustic Properties File for this acoustic element and will set the appropriate scattering coefficients depending upon where the non−reflecting acoustic element is located. Phasing of the modes through internal non−reflecting regions is not taken into account at this time.
- IUPSTR: Interface plane just upstream of the acoustic element (=0 means that it is connected to the far−field).
- IDWNST: Interface plane just downstream of the acoustic element (=0 means that it is connected to the far−field). Note that if this value is zero then the code will stop and not read other regions. Thus, the aft most acoustic element should be input last.

4.2.2.2 System File Assumptions

- There can be a maximum of one rotating blade row, one stationary blade row, one inlet radiation acoustic element and one aft radiation acoustic element. Less than this number of acoustic elements is also allowable. Non−reflecting acoustic elements can be placed at any point in the system. However, for internal non−reflecting acoustic elements, the noise is *not* phase shifted through the acoustic element at this time.

- Acoustic elements may be input into the System File in any order. However, the neighboring acoustic elements must be given somewhere in the file. The most aft acoustic element must be input last and must either be non−reflecting or be an aft radiation acoustic element. In addition, the forward most acoustic element must either be non−reflecting or be an inlet radiation acoustic element.
- The code assumes that all acoustic elements were created with the same number of rotor blades (NBLADE), stator vanes (NVANE), and corrected fan rotational tip speed (VTIPC) (see Section 4.2.3.1). Hub to tip ratios at the interface planes should be the same for the two connecting acoustic elements for the modes to be passed correctly between regions. The code, however, does not prevent hub to tip ratios from differing from region to region.
- The code presently assumes that all acoustic elements are in a single duct (such as in Figure 1). The concept of a primary duct and bypass duct is not implemented in the code.
- It is assumed that there is no more than one inlet radiation acoustic element and one aft radiation acoustic element being used in any given calculation. If there are more, the code will overwrite one of them and will write an error stating the problem.
- For multiple cases the code is written so as to assume that all cases are being run in order by CUP3D. The same order is assumed for all acoustic elements. e.g. if multiple cases were run by a stator code in a different order than was run by a rotor code, then CUP3D will not run correctly.
- It is assumed that the user has chosen an origin for the entire calculation and that the origin is consistent for all Acoustic Properties Files being input into CUP3D. Far−field files should utilize this origin to specify distance from the engine and angles around the engine.

4.2.2.3 CUP3D System File Examples

Example 1: No Non–reflecting Acoustic Elements

```
This is an sample file for this system
   NHARM       NCASE          DFAN           PINF        TINF
     3           1           17.26          14.696      536.67
  Region     File Name   Upstream  Interface   Downstream  Interface
     1        'inlrad'          0                      1
     2         'rotor'          1                      2
     3        'stator'          2                      3
     4        'aftrad'          3                      0
```

Example 2: The Last Acoustic Element is Non–reflecting

```
This is an sample non-reflecting file for this system
   NHARM       NCASE          DFAN           PINF        TINF
     3           1           17.26          14.696      536.67
  Region     File Name   Upstream  Interface   Downstream  Interface
     1        'inlrad'          0                      1
     2         'rotor'          1                      2
     3        'stator'          2                      3
     4       'NONREFL'          3                      0
```

4.2.3 Acoustic Properties File

Acoustic Properties Files are output by rotor, stator, inlet radiation and aft radiation computer codes for input into CUP3D. An Acoustic Properties File is required for each reflecting acoustic element in the system. No Acoustic Properties File is needed for a non−reflecting element.

A computer code will create an Acoustic Properties File and will place the following information in the file in the order shown below. Note that the computer code generating this file is designated by a specific type (ICODE) which identifies the code to the user.

The parts of the Acoustic Properties File are:

- **Header Cards:** Contain information about the run including the computer code which created the file, the acoustic modes contained in the file, and certain geometry and performance of the acoustic element. This information identifies, for the user, the configuration run.
- **Scattering Coefficients:** These are the reflection and transmission coefficients of the acoustic element. Definitions for these coefficients are given in Reference 3 along with a method for creating them.
- **Source Vector:** The source vector is output if the acoustic element is influenced by an outside force such as a wake interacting with a vane or blade. In this case acoustic mode amplitudes and vorticity waves are created which form the source vector and are placed in the Acoustic Properties File. Definitions for these coefficients are given in Reference 3.
- **Far−field Directivities:** If the acoustic element radiates noise to the far−field, then far−field directivities are placed in the Acoustic Properties File. Pressure directivities result from unit input for each duct mode into a radiation code. These directivities are given at a constant radius, R, from a user specified origin.

Note that in this file, all length dimensions are non−dimensionalized by the fan tip diameter (inches) at the fan leading edge, DFAN. All Temperatures are non−dimensionalized by the static temperature (^{0}R) in the far−field (far from the nacelle), TINF. All Pressures are non−dimensionalized by static pressure (psia) in the far−field (far from the nacelle), PINF.

This file is potentially user readable (though is not easy to read) using the Acoustic Property File information in Reference 3. The first five cards of a file are repeated below for the information of the user. Unless otherwise specified below, all file information is read in free format. Note that a ✻ denotes parameters which must have the same value from acoustic element to acoustic element for the CUP3D code to run correctly.

4.2.3.1 First Five Header Cards in Acoustic Properties files

Card 1: (for multiple cases this card is output only once with the first case)

- ICODE: Computer Code which created this file

  Note: ICODE is designed so that the first number denotes the type of code which created this file. The second number refers to which code created this file. For example: ICODE = 11: The first 1 refers to inlet radiation codes, the second 1 refers to the Eversman inlet radiation code.

=10 Other Inlet Radiation Code

=11 Eversman Inlet Radiation Code

=12 Caruthers Inlet Radiation Code

=20 Other Aft Radiation Code

=21 Eversman Aft Radiation Code

=22 Caruthers Aft Radiation Code

=30 Other Rotor Code

=31 SOURCE3D Rotor Code

=40 Other Stator Code

=41 SOURCE3D Stator Code

- NCASE: Number of “cases” where a case is defined as all harmonics for a given geometry and fan operating condition. Acoustic properties files are read in the order ICASE = 1, NCASE (see Card 2).

Card 2: ICASE: Case Number: FORMAT(1X,’Case Number’,I3)

Card 3: CODETITLE: Title Card − identifying the case. Use the title from the code which was run. FORMAT(A80).

Card 4:

- NHT: Number of Harmonics run.

∗ VTIPC: Corrected Fan Rotational tip speed (ft/sec).

where: $$VTIPC = \frac{\pi}{720} N_{1_c} (DFAN)$$

DFAN = Fan tip diameter (inches) at the fan leading edge

$$N_{1_c} = \text{Corrected Fan Rotational Speed (rpm)} = \frac{N_1}{\sqrt{\frac{T_{o1}}{518.67}}}.,$$

N_1 = Fan Rotational speed (rpm)

T_{o1} = reference temperature (^{0}R) used to correct the fan speed to a “standard day”. For zero Mach Number in the far−field, this temperature is the static far−field ambient temperature.

Card 5:

∗ NBLADE: Number of Rotor Blades

∗ NVANE: Number of Stator Vanes.

4.3 OUTPUT FILE STRUCTURE

The CUP3D Fan Noise Coupling Code creates up to three output files.

The output files will be of the following format:

Output File	**Output File Name**	**When Created**	**What is in it?**
General Output	user named	Always	Information identifying acoustic property files used Selected geometry and performance for each acoustic element Modes used in Prediction Mode power levels Total power levels
Far Field Directivity File	farfld.data	When far−field acoustic elements are used	Inlet, aft, and total directivities for each harmonic Circumferential Mode directivities Radial Mode directivities
Total Sound Power Level File	powerout.input	When multiple cases are run	Corrected fan speed blade and vane numbers Inlet, aft and total power levels for first three harmonics

4.4 RUNNING THE CODE

To run CUP3D:

1. Insure that the cup3d executable located in the "TFaNS1.5/bin" subdirectory has been sourced.

2. Bring up a command tool in the subdirectory where the system file and acoustic properties files are located.

3. Type:

   cup3d<input_filename>output_filename &

   where:

   input_filename is the user's system file name.

   output_filename is the file name (chosen by the user) where the general output will be placed.

   The '&' permits the code to run in background. If the '&' is not included above, then the code will not run in background.

5. SOURCE3D ROTOR WAKE/STATOR INTERACTION CODE

5.1 GENERAL INFORMATION

The SOURCE3D code (Reference 4) is an improved and enhanced version of the V072 Rotor wake/stator interaction code (References 12, 13, and 14) which calculates the acoustic information required by CUP3D for the rotor and the stator (see Section 4.1).

SOURCE3D includes the effects of solid body swirl and flow turning to predict:

- Fan wake/FEGV interaction source noise
- fan scattering coefficients
- FEGV scattering coefficients

The wake used by the code may include a semi−empirical tip vortex or preliminary hub vortex.

Wakes harmonic amplitudes may also be brought in from an outside source e.g. CFD wakes or measured wake data. Format for this wake input is given in Section 5.2.10. The AWAKEN code can be used to convert a standard SOURCE3D input file into one which includes wake input from an outside source. AWAKEN and its options are discussed further in Section 8.

The SOURCE3D program may be run in the workstation environment. The namelist input is used in this program where multiple cases may be run by simply stacking one namelist input above another. The code presently requires geometry and performance parameters as a function of radius across the fan and FEGV.

5.2 INPUT FILE STRUCTURE

The SOURCE3D rotor wake/stator interaction code uses Namelist input. It gives flexibility to the user in entering the data. It does not require all possible input be in the data file. Variables can be left out of the input file with ease. Thus minimal input from the user is required.

5.2.1 General Namelist Input

The following is a general description of how the input file for SOURCE3D is set up:

1. Title − this can be up to 80 characters in length and is the title for the case being run. If a title is going to be entered it must be input before the Namelist data. If no title is entered the program will use a default title based on the case being run.

2. The namelist data section of the input file is to be set up as follows :

   - Column 1 of each line must be blank.
   - All data must start in column 2
   - The first line of a namelist set of data must contain &INPUT The data may be entered starting on the same line as the &INPUT or on the next line. If it is to be entered on the same line as the &INPUT a blank space must separate the data from the &INPUT.
   - The data is to be entered separated by commas. As much data as fits can be entered on a single line and the order of the variables is irrelevant.

- The form of the data is VARIABLE NAME = DATA VALUE or , ARRAY NAME = DATA VALUES (Each element separated by a comma). The last line of a set of data must contain &END

Multiple cases can be input in the same data file by stacking each case as if they were set up in separate files. Each case needs its own namelist input. Only those items that need to change from the previous case must be defined in the new namelist set. Once each case is defined they can be stacked on top of each other in the file.

For more information regarding the set up of the input data file refer to the examples in Section 5.6.

5.2.2 Creating Rotor and Stator Acoustic Elements

To calculate rotor and stator scattering coefficients, CUP3D requires us to create rotor and stator acoustic elements (See Section 4.). A variation on Figure 5 is shown in Figure 6 and denotes the rotor and stator acoustic elements (Regions 2 and 3 in Figure 5).

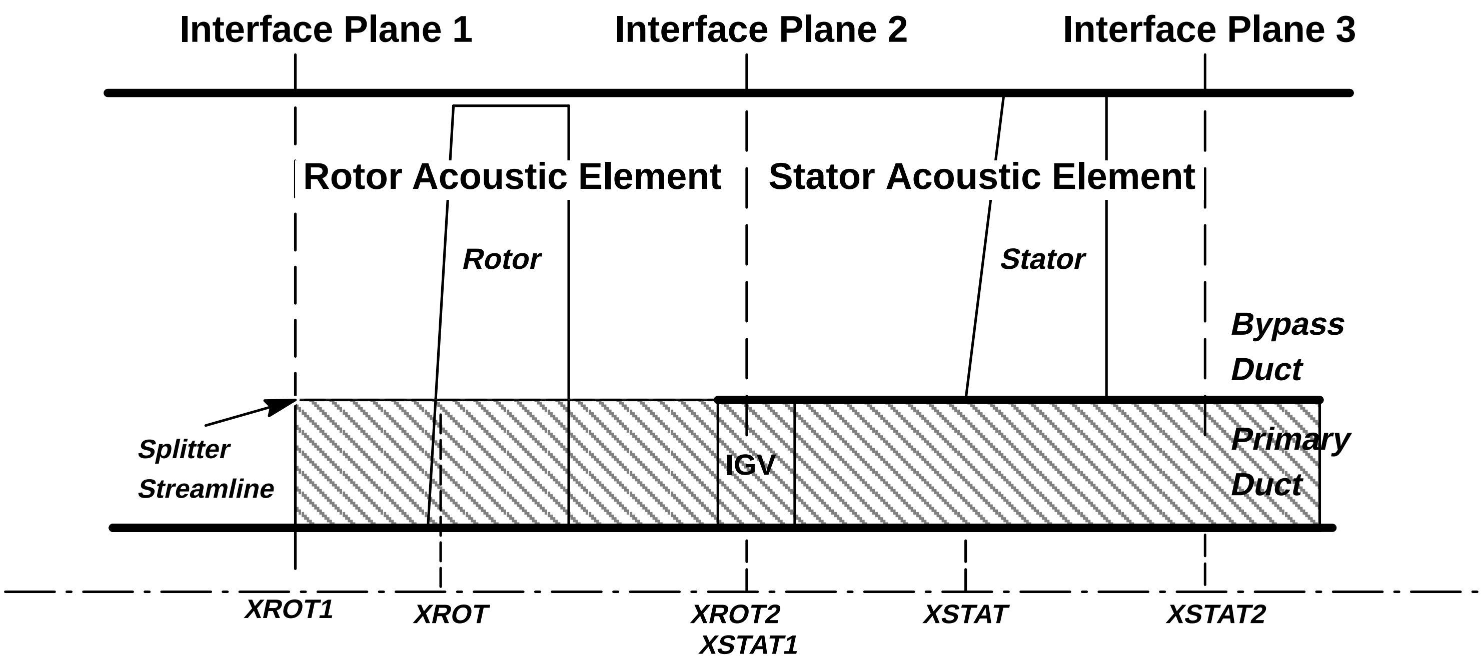


Figure 6: CUP3D Acoustic Element and interface plane definitions

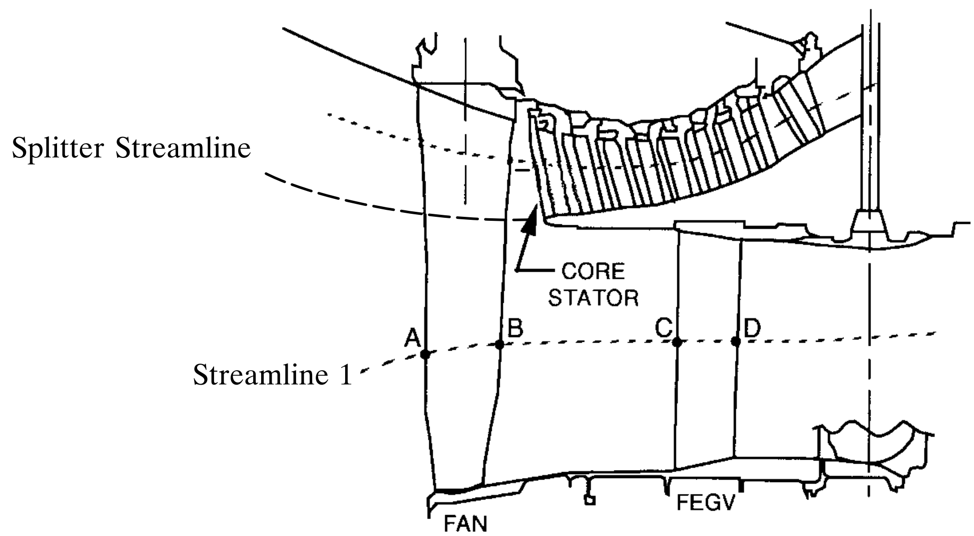
In this figure the interface planes must be located axially relative to a user defined origin. The rotor and stator must also be located axially in the acoustic elements. These locations are defined by the stator leading edge hub location (XSTAT), and the rotor leading edge splitter streamline location (XROT), shown in Figure 6. These parameters define the origin of the calculation and the location of the rotor relative to the stator. The interface planes are located axially using XROT1, XROT2, XSTAT1 and XSTAT2. See Sections 5.2.7 and 5.2.8 for more information.

5.2.3 Creating a Streamline Input

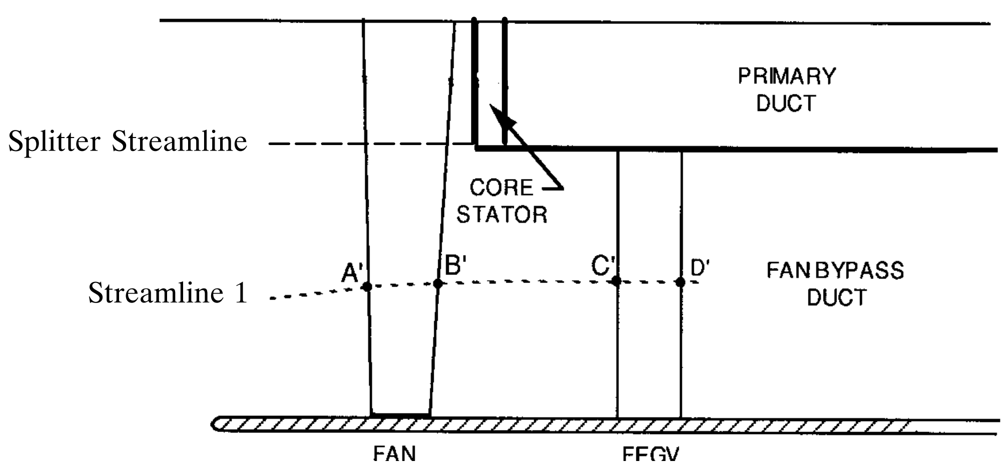
For the purposes of this discussion, a sample engine geometry is shown in Figure 7. To obtain input to SOURCE3D we need to first transform our real engine geometry (Figure 7a) into a constant area duct geometry (Figure 7b). Note that SOURCE3D does not presently contain the ability to calculate core stator noise. Thus the duct assumes the splitter streamline to be the hub wall. To obtain Figure 7b

from Figure 7a, visualize each streamline like a “string” with geometry and performance varying along the “string.” Now pull the string so it is taught where the radius of the string from the engine centerline corresponds to the rotor leading edge radius of this streamline.

Thus, each streamline is located at the rotor leading edge radius to create the constant area duct. We then follow along each streamline back to the stator to obtain engine geometry and performance parameters.



(a) Full Scale Engine Geometry



(b) SOURCE3D Full Scale Engine Geometry

Figure 7: Full Scale Engine Geometry Vs. SOURCE3D Representation

For example:

Looking at Figure 7, streamline 1: to get from Figure 7a and Figure 7b look at the streamline radius at point A in Figure 7a. This radius will be the radius of the streamline in the program. Therefore utilize geometry and performance at points A,B,C,D. Identify the rotor chord along point A to B and the stator chord from point C to D respectively (this is the aerodynamic chord). Do not use the axial chord. Use the aerodynamic chord as defined on a streamline. Use the rotor stagger angle at an airfoil cross−section starting at point A. Use the stator stagger angle at an airfoil cross−section starting at point C. Identify the axial spacing as the streamline distance from points B to C.

For more information on the choice of radial locations see Part 1 of Reference 12. Note that if the radial change on the engine from the rotor leading edge to the stator leading edge is significant a program streamline radial location other than the rotor leading edge may be desirable.

5.2.4 Standard Input Data Units

Standard Input Data Units

- Lengths −−− Inches
- Rotor speed −−− RPM
- Temperatures −−− Degrees Rankin
- Densities −−− lb_m/ft^3
- Pressures −−− lb_f/ft^2
- Angles −−− Degrees

All air and stagger angles are defined relative to the circumferential direction.

5.2.5 Case Descriptive Input Parameters

ISTAGE – Type of Prediction

= 1 Rotor and Stator Acoustic Properties Files are created (default)
= 2 Only the Rotor Acoustic Properties File is created
= 3 Only the Stator Acoustic Properties File is created

IPRED – Interaction being predicted

= 0 Rotor Wake Calculation only
= 1 Rotor/Stator or Fan/FEGV interaction only (default)

NDATS – No. of streamlines where streamline information will be input for a rotor/stator or rotor/FEGV interaction

ICASE – The number of cases being run (default = 1)

NHT – The number of BPF harmonics where noise is being calculated (default = 3)

IWAKE – Chooses Wake width and velocity deficit correlations to be used

= 0 Use upwash wake data as input (see Section 5.2.10)
= 1 Loaded fan wake profile (default)
= 2 Linear rational function for rotor wake profile
= 3 GE 1995 Wake Model

ISHAPE – Wake Tangential profile option (if IWAKE > 0, See Section 5.2.15, Note 1)

= 1 Hyperbolic Secant profile
= 2 Gaussian profile
= 3 Loaded fan wake profile (default)

ITPVTX – Tip Vortex option (if IWAKE > 0)

= 0 Tip Vortex not included in calculation (default)
= 1 Calculation includes a Tip Vortex

IHBVTX – Hub Vortex option (if IWAKE > 0)

= 0 Hub Vortex not included in calculation (default)
= 1 Calculation includes a Hub Vortex

IPRINT – Print option (if IWAKE > 0)

= 0 Short output file (Does not print detailed wake profile and vortex information).
= 1 Long output file (Prints wake profile details and vortex information).

5.2.6 General Geometry and Performance Input

Variable Name	Needed as input for ISTAGE option:			Variable Type	Description
	1	2	3		
NBLADE	x	x	x	INTEGER	No. of rotor blades
NVANES	x	x	x	INTEGER	No. of stator vanes (or FEGV's)
DDUCT	x	x	x	REAL	Outer duct diameter at rotor l.e.
N1C	x	x	x	REAL	Corrected rotor speed (see Section 5.2.15, Note 2)
T01	x	x	x	REAL	Total temperature at engine or rig inlet (see Section 5.2.15, Note 2)
TAMB	x	x	x	REAL	Ambient temperature (default = 518.67^{o}R)
PAMB	x	x	x	REAL	Ambient pressure (default = 2116.22 lb_f/ft^2)
EPSIL	x	x	x	REAL	Determines the number of cutoff modes to be used in the calculation. EPSIL is the maximum value the mode decay coefficient (value in the exponential) can become before a mode amplitude will no longer be calculated. (default = 3.0)

5.2.7 Rotor Scalar Geometry and Performance

Axial direction is positive downstream of a user defined origin. Rotor Scalar Geometry and Performance defines the conditions in the rotor acoustic element under which acoustic modes propagate in the duct and couple to the unsteady pressure distributions.

Variable Name	Needed as input for ISTAGE option: 1	2	3	Variable Type	Description
XROT	x	x	–	REAL	axial location, rotor l.e. at hub or splitter streamline relative to user defined origin (see Figure 6) (if set to 10000.0, SOURCE3D assigns this value calculated based on BROTOR, ALPHCHR, XSPAC, using XSTAT as the origin)
XROT1	x	x	–	REAL	axial location, interface plane upstream of the rotor relative to user defined origin (see Figure 6) (if set to 10000.0, SOURCE3D assigns this value as the furthest forward point on the rotor l.e based on BROTOR, ALPHCHR, XSPAC, YRD, YRLED, XRLED using XSTAT as the origin)
XROT2	x	x	–	REAL	axial location, interface plane downstream of the rotor relative to user defined origin (see Figure 6) (if set to 10000.0, SOURCE3D assigns this value: if ISTAGE = 1: mid−point between the rotor t.e. hub and stator l.e. hub based on XSPAC if ISTAGE = 2: one fan hub chord downstream of the rotor t.e. hub)
MAI	x	x	–	REAL	Mass averaged axial Mach No., rotor l.e.
TSI	x	x	–	REAL	Mass averaged static temperature, rotor l.e.
RHOI	x	x	–	REAL	Mass averaged static density, rotor l.e.
MAR	x	x	–	REAL	Mass averaged axial Mach No., rotor t.e.
TSR	x	x	–	REAL	Mass averaged static temperature, rotor t.e.
RHOR	x	x	–	REAL	Mass averaged static density, rotor t.e.
RSWR	x	x	–	REAL	Reference radius specifies solid body swirl in rotor acoustic element. Turn off swirl by setting equal to 1.0. (See Section 5.2.15, Note 3)
MRSWR	x	x	–	REAL	absolute Mach No. at radius, RSWR, rotor t.e.
ALPHASWR	x	x	–	REAL	absolute air angle at radius, RSWR, rotor t.e.

5.2.8 Stator Scalar Geometry and Performance

Axial direction is positive downstream of a user defined origin. Stator Scalar Geometry and Performance defines the conditions in the stator acoustic element under which acoustic modes propagate in the duct and couple to the unsteady pressure distributions.

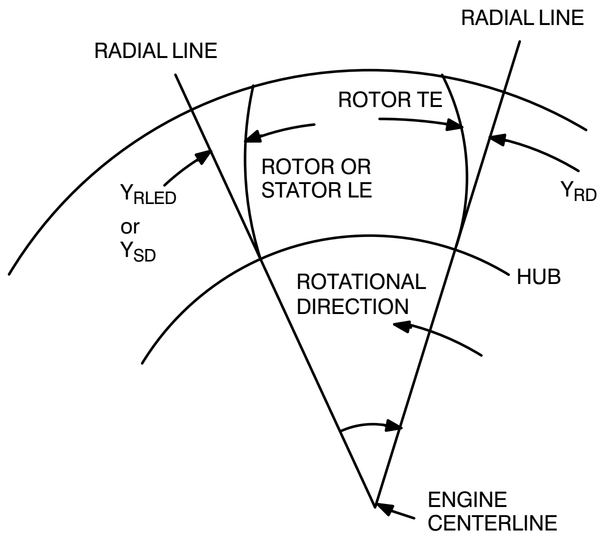
Variable Name	Needed as input for ISTAGE option:			Variable Type	Description
	1	2	3		
XSTAT	x	–	x	REAL	axial location, stator l.e. at hub relative to user defined origin (see Figure 6) (if set to 10000.0, SOURCE3D assigns this value to 0.0)
XSTAT1	x	–	x	REAL	axial location, interface plane upstream of the stator relative to user defined origin (see Figure 6) (if set to 10000.0, SOURCE3D assigns this value as the mid–point between the rotor t.e. hub and stator l.e. hub based on XSPAC)
XSTAT2	x	–	x	REAL	axial location, interface plane downstream of the stator relative to user defined origin (see Figure 6) (if set to 10000.0, SOURCE3D assigns this value as the furthest downstream stator t.e. point as calculated from BSTATR, ALPHCH, YS, XS)
MAS	x	–	x	REAL	Mass averaged axial Mach No., stator l.e.
TSS	x	–	x	REAL	Mass averaged static temperature, stator l.e.
RHOS	x	–	x	REAL	Mass averaged static density, stator l.e.
MAE	x	–	x	REAL	Mass averaged axial Mach No., stator t.e.
TSE	x	–	x	REAL	Mass averaged static temperature, stator t.e.
RHOE	x	–	x	REAL	Mass averaged static density, stator t.e.
RSWS	x	–	x	REAL	Reference radius specifies solid body swirl in stator acoustic element. Turn off swirl by setting equal to 1.0. (See Section 5.2.15, Note 3)
MRSWS	x	–	x	REAL	absolute Mach No. at radius, RSWS, stator l.e.
ALPHASWS	x	–	x	REAL	absolute air angle at radius, RSWS, stator l.e.

5.2.9 Streamline Geometry and Performance Input

These parameters should be input for NDATS number of streamlines. All input radii must be specified starting at the rotor splitter streamline radius and ending with the rotor tip streamline radius (see Figure 6). If no splitter exists, then radii must be specified starting at the rotor hub streamline radius.

Variable Name	Needed as input for ISTAGE option: 1	2	3	Variable Type	Description
RADIUS	x	x	x	REAL	Radius of streamline; rotor l.e. (See Section 5.2.15, Note 4)
XSPAC	x	–	x	REAL	Rotor t.e. to stator l.e. axial spacing
Rotor Geometry and Performance					
BROTOR	x	x	x	REAL	Rotor aerodynamic chord
ALPHCHR	x	x	–	REAL	Rotor stagger angle (See Section 5.2.15, Note 5)
YRLED	x	x	–	REAL	Non–radial variation, rotor l.e. (see Figure 8)
XRLED	x	x	–	REAL	Axial variation, rotor l.e. (see Figure 9)
YRD	x	x	x	REAL	Non–radial variation, rotor t.e. (see Figure 8)
BETA1D	x	–	x	REAL	Relative flow angle, rotor l.e.
BETA2D	x	–	x	REAL	Relative flow angle, rotor t.e.
OMEGA	x	–	x	REAL	Rotor loss coefficient, $\overline{\omega}$ (if IWAKE > 0) (See Section 5.2.15, Note 6)
MX	x	–	x	REAL	Axial Mach no., rotor l.e.
MRABSR	x	x	–	REAL	Relative Mach No., average of Rotor l.e. & t.e (See Section 5.2.15, Note 5)
Stator Geometry and Performance					
BSTATR	x	–	x	REAL	Stator aerodynamic chord
ALPHCH	x	–	x	REAL	Stator stagger angle (See Section 5.2.15, Note 7)
YSD	x	–	x	REAL	Non–radial variation, stator l.e. (see Figure 8)
XSD	x	–	x	REAL	Axial variation, stator l.e. (see Figure 9)
ACLS	x	–	x	REAL	Relative flow angle, stator l.e.
MRABS	x	–	x	REAL	Absolute Mach no., stator l.e.

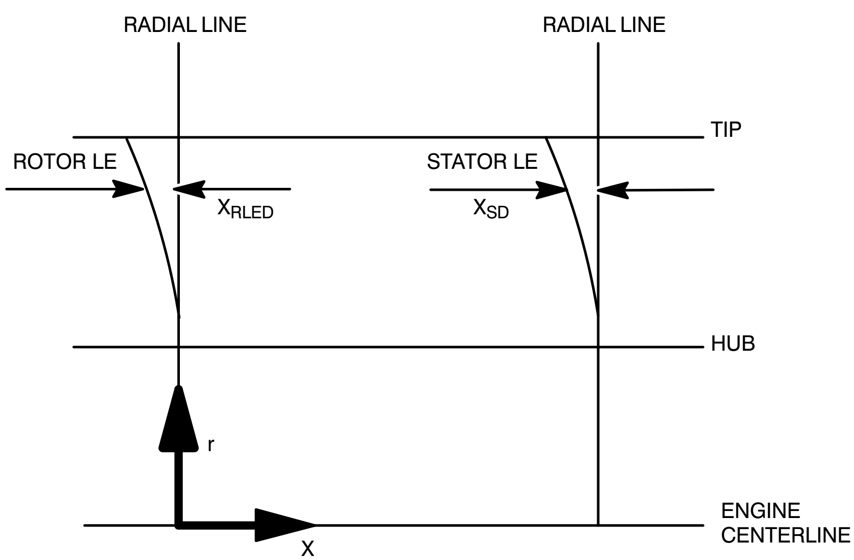
Schematic View of a Rotor Blade TE and a Rotor blade or Stator Vane LE Looking Down the Turbofan X AXIS, in Stator−fixed Coordinates



Y_{RLED} or Y_{SD} is positive in the direction opposite rotor rotation.
Y_{RD} is positive in the direction of rotor rotation.

Figure 8: Definition of Y_{RD}, Y_{RLED} and Y_{SD}

Schematic View of a Rotor Blade LE and Stator Vane LE Looking Perpendicular to the Rotor Axis.



XRLED is positive when the rotor l.e. moves further upstream relative to the hub
XSD is positive in the direction of reducing the axial spacing relative to the hub streamline.

Figure 9: Definition of X_{SD} and X_{RLED}

5.2.10 Inputting Wake Upwash Velocity Profiles (if IWAKE = 0 only)

SOURCE3D permits the user to input the complex wake upwash harmonic amplitudes obtained from an outside source (e.g. wake data). Up to the first nine harmonics of the wake upwash velocity Fourier coefficients may be input. Note that wake upwash harmonic amplitudes should be specified from the stator hub to the stator tip. NWAKE is a scalar quantity the other quantities are vector quantities.

In a namelist format the complex wake upwash harmonic amplitudes are specified as follows (using WAKHRM1 as an example):

WAKHRM1 = (real part at 1st % span, imaginary part at 1st % span),
(real part at 2nd % span, imaginary part at 2nd % span), . . .,
(real part at NWAKE % span, imaginary part at NWAKE % span),

If the AWAKEN code is used prior to running SOURCE3D, AWAKEN will automatically place these parameters in the correct format in its SOURCE3D output file (See Section 8.).

An example of the wake input format is given in Section 5.6.

Variable Name	Needed as input for ISTAGE option:			Variable Type	Description
	1	2	3		
NWAKE	x	–	x	INTEGER	Number of radial locations where wake information is given
PCTWAKE	x	–	x	REAL	Stator percent spans where wake data is given (should start at 0% span and end at 100% span)
WAKHRM1 WAKHRM2 WAKHRM3 WAKHRM4 WAKHRM5 WAKHRM6 WAKHRM7 WAKHRM8 WAKHRM9	x	–	x	COMPLEX	Wake upwash harmonic amplitudes non–dimensionalized by the absolute freestream velocity for harmonics 1 through 9. Only wake harmonics from 1 to NHT need to be specified. Input is limited to the first nine wake harmonics. The number at the end of each of these variable names denotes the BPF harmonic of the wake upwash harmonic amplitude (i.e. WAKHRM7 refers to the wake harmonic amplitude for the 7th BPF harmonic).

5.2.11 Hub Vortex Parameters (if IWAKE > 0 and IHBVTX = 1)

It is important to realize that the hub vortex model is only partially developed from the technical standpoint. Reference 14 will give details but essentially the empirical correlations for this vortex do not exist so the code either uses tip vortex relations or it sets values equal to a constant.

Because of the preliminary nature of this option, extreme care should exercised when it is used. The following scalar quantities are needed:

Variable	Variable Type	Description
DHUB	REAL	Rotor l.e. hub diameter
SBNH	REAL	Tangential distance of vortex center from rotor wake pressure side divided by the rotor pitch at the hub (default = 0.5)
BRHUB	REAL	Hub rotor aerodynamic chord
MXHUB	REAL	Axial Mach no., rotor l.e. hub streamline
BETA1H	REAL	Relative flow angle, rotor l.e. hub streamline
BETA2H	REAL	Relative flow angle, rotor t.e. hub streamline

5.2.12 Tip Vortex Parameters (if IWAKE > 0 and ITPVTX = 1)

In this section, TAUG, SBNT are not readily available. However estimates of their values can be made. See Section 5.2.16 for more information. The following scalar quantities are needed:

Variable	Variable Type	Description
TAUG	REAL	Rotor tip clearance gap
SBNT	REAL	Tangential distance of vortex center from rotor wake pressure side divided by the rotor pitch at the tip (default = 0.5)
BRTIP	REAL	Tip rotor aerodynamic chord
		(set by the code if IPRED = 0, 1)
MXTIP	REAL	Axial Mach no., rotor l.e. tip streamline
BETA1T	REAL	Relative flow angle, rotor l.e. tip streamline
BETA2T	REAL	Relative flow angle, rotor t.e. tip streamline

5.2.13 Program Overriding Parameters

These are scalar quantities.

Variable Name	Default Value	Description
EC	0.0001	Convergence criteria to calculate X_{mn} ($k^*_{m\mu}$ in Tyler/Sofrin, Reference 15)
NRADS	*	No. of radial integration stations; Must be an odd no. (maximum: 99)
NCHORR	*	No. of chordwise integration stations on the rotor; Must be an even no. (maximum: 60)
NCHRS	*	No. of chordwise integration stations on the stator; Must be an even no. (maximum: 60)

* CALCULATED USING A CRITERIA CALCULATION IN THE PROGRAM. If this variable is used in a multi−case run, it must be input for all cases separately. Otherwise the code will automatically override.

5.2.14 Developmental Parameters (if IWAKE > 0 only)

These parameters may be used to effect the wake harmonic magnitudes. Since they are developmental in nature, it is not recommended that they be used.

Variable Name	Description
WTIV	Rotor inviscid velocity gradient/rotor wheel speed (negative value accounts for rotor loading) (default = 0.0)
BETAW	Wake flow angle variation parameter (default = 0.0)
VVTR	CRP parameter: rotor 2 fan speed / rotor 1 fan speed (default = 0.0)
WKEFAC	Multiplier for wake width correlation (WAKEWTH=WKEFAC*WAKEWTH) (default = 1.0)
VELFAC	Multiplier for velocity deficit correlation (VELDEF=VELFAC*VELDEF) (default = 1.0)

5.2.15 Notes On Input

1. ISHAPE: The wake profile shape is defined by the variable ISHAPE. The best value for this shape is a function of the streamwise spacing to chord (SSOC in the output file). The Loaded Wake profile (ISHAPE = 3) is best used for streamwise spacing to chords of less than 4. For streamwise spacing to chords of greater than 4 the Hyperbolic secant wake profile (ISHAPE = 1) is the best profile to use.

2. N1C: N1C is the corrected rotor speed. It, combined with T01, is used to calculate N1, the uncorrected rotor speed where:

$$N1 = N1C\sqrt{\frac{T01}{518.67}} \tag{3}$$

3. RSWR, RSWS: These parameters give the radii which define solid body swirl for the rotor and stator acoustic elements (RSWR for the rotor; RSWS for the stator). Swirl Mach numbers at these radii are calculated using the Mach numbers and air angles input by the user (i.e. MRSWR, ALPHASWR for the rotor, and MRSWS, ALPHASWS for the stator). These swirl Mach numbers are then scaled from these radii to the tip radius using a solid body swirl assumption. This determines the solid body swirl Mach number at the tip of the rotor or stator.

4. RADIUS: RADIUS defines the streamline radii which will identify the constant area duct to be utilized by the program. RADIUS has been defined at the rotor leading edge. However if the fan duct shows significant convergence or radius change from the rotor to the stator then it may be desirable to redefine the RADIUS at another axial location. See Part 1 of Reference 12 for a more complete discussion of this parameter. Note: If RADIUS is defined at an axial location other than the fan l.e. then DDUCT must be set equal to twice the tip radius at the location used.

5. MRABSR, ALPHCHR: The rotor relative Mach number and stagger angle may be expressed using a number of different parameters. The method chosen here is to set

   MRABSR = average of rotor l.e. and rotor t.e. relative Mach numbers

   ALPHCHR = angle the chord of the rotor airfoil section makes with the circumferential direction (alpha chord)

6. OMEGA= Rotor Loss Coefficient (see Reference 16) in the relative reference frame (fixed to the rotor) where:

$$\overline{\omega} = \frac{P_{o2_{ideal}} - P_{o2}}{P_{o1} - P_1} = \frac{\text{Ideal Total Pressure at Fan t.e.} - \text{Actual Total Pressure at Fan t.e.}}{\text{Total Pressure at Fan l.e.} - \text{Static Pressure at Fan l.e.}}$$

7. ALPHCH: The stator stagger angle may be expressed using a number of different parameters. The method chosen here is to use the stagger angle defined as follows:

$$\text{ALPHCH} = 90 - \arctan\left[\frac{\tan(90 - \text{stagger}) + \tan(90 - \beta_1^*)}{2}\right]$$

   where:

   stagger = angle the chord of the stator airfoil section makes with the circumferential direction (alpha chord)

   β_1^* = leading edge metal angle relative to the circumferential direction

This angle is chosen because it is effectively the angle of the airfoil at the quarter chord point.

Stagger may be approximated by:

$$\text{stagger} = 90 - \arctan\left[\frac{\tan(90 - \beta_1^*) + \tan(90 - \beta_2^*)}{2}\right]$$

where:

β_2^* = trailing edge metal angle relative to the circumferential direction

5.2.16 Tip Vortex Parameter Information (if IWAKE > 0 and ITPVTX = 1)

Reference 14 describes the tip vortex model which is a simple semi−empirical model. There are two important parameters in this model which are not easily determined:

SBNT = Circumferential location of the tip vortex relative to the pressure side of the wake of a nearby blade divided by the blade pitch.

TAUG = Rotor blade tip clearance

TAUG is quite important as it determines the vortex strength and contributes to determining the vortex radius. A couple of notes:

- In a real engine TAUG varies around the circumference.
- In a real engine TAUG varies with engine condition.
- In SOURCE3D a constant TAUG is assumed at a given engine condition.

SBNT refers to the circumferential location of the tip vortex relative to the pressure side of the wake of a nearby blade normalized by the blade pitch (see Figure 10). We can explain the development of this parameter as follows:

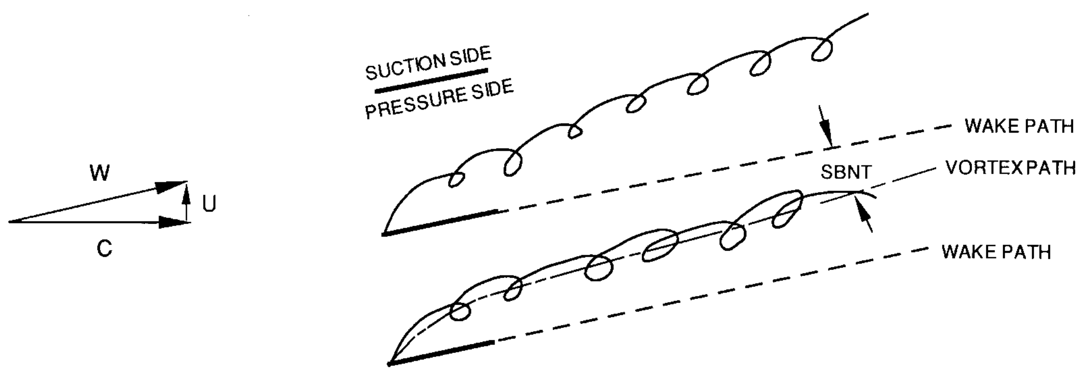


Figure 10: Tip Vortex Location, SBNT

Wakes from each blade are convected downstream along some path (Figure 10). Near the tip, at or near the blade leading edge a vortex develops as a result of the interaction between the blade and tip leakage. This vortex convects along some path toward the stators (Figure 10). As it convects it moves away from the suction side of the blade where it was generated and toward the pressure side of the neighboring blade wake.

SBNT is also never known nor can we estimate it. However we do know the effect of the placement of the vortex on the harmonic content of the stator upwash. If SBNT=0.5 then the vortex is half way between two wakes. Consequently, two velocity deficits are created per passage in the tip region, one from the vortex and the the other from the wake. This will cause any tip generated 2BPF noise to dominate. If SBNT=0.0 then the vortex velocity deficit adds on top of the wake velocity deficit. This causes a rise in all harmonics where BPF noise > 2BPF noise > 3BPF noise. Reference 14 studies this effect in detail.

5.3 OUTPUT FILE STRUCTURE

The Rotor Wake/Stator Interaction program creates three output files. The General output file is a mandatory output file but the IPRINT input option allows for this file to be either a long output file or a short one.

The Rotor and Stator Acoustic Properties files are output for use by the CUP3D Fan Noise Coupling Code discussed in Section 4.

The output files will be of the following format:

Output File	**Output File Name**	**Output File Extension**	**What is in it?**
General output	Same name as user's input file	s3dout	Wake Information Cutoff ratio information, upstream and downstream of fan and FEGV's Power level and mode amplitude information (normalized based on modes in Ref. 13) for the stator only with swirl but without turning
Rotor Acoustic Properties File (for CUP3D)	Same name as user's input file	s3drot	For the fan: Header cards Scattering coefficients
Stator Acoustic Properties File (for CUP3D)	Same name as user's input file	s3dsta	For the FEGV: Header cards Scattering coefficients Source vector

5.4 ERROR MESSAGES OUTPUT

The program will output a number of different types of error messages to signal possible problems with the program answers. There are two areas in the code where these error messages are generated: 1) during the calculation of the radial mode shape, 2) during the rotor and stator dipole strength calculation while solving the set of simultaneous equations (as a matrix) . The mode shape calculation errors will identify the problem along with the absolute value of the circumferential mode number, m and the radial mode number, μ of the effected radial mode. In large part these errors signal where minor problems have occurred and in most cases the user should simply check the answers for the mode shapes for the modes where these errors occur to see that these errors are in fact insignificant.

There are four types of errors: NOTES, WARNINGS, and FATAL ERRORS, and errors indicating that the number of radial integration stations or chordwise integration stations (for the rotor or stator) required by the code's criteria are greater than the code's dimension statements.

- "NOTES" notify the user that a Bessel function subroutine has calculated an answer which has gone to plus or minus machine infinity according to these subroutines. These errors are just there to inform the user of this fact. These errors do not in and of themselves signal a real problem.
- "WARNINGS" are more serious. They relate to one of two things: The critical Mach no. (radial mode eigenvalue) calculation did not converge, or the rotor or

stator dipole distribution matrix inversion is ill conditioned. In these cases the accuracy of the answers may be effected. Perhaps the least worrisome warning is when the critical Mach number does not converge. Normally the critical Mach number is correct to the accuracy specified by the parameter EC (See Section 5.2.13). However, the criteria is quite stringent and will sometimes cause this error. Note that when this error does occur it is important to check the radial mode shape and to check the radial mode power levels for the mode where this occurs. This is because while the critical Mach number may be good, when this error occurs there is usually some computer roundoff error which will effect the radial mode shape. In most cases this error is much smaller than the noise which propagates from the important modes. This error is most likely to occur when the hub/tip ratio is less than 0.4. See Reference 12 for more information.

If the rotor or stator dipole matrix distribution warning occurs it is important that the engineer and the programmer responsible for this program be contacted. This error indicates that the accuracy of this matrix solver is poor. This error occurs because a value along the matrix diagonal is much smaller than one off the diagonal. This can effect the program error. This error has not occurred for the cases tried. However, an increase in the matrix condition number has been observed as the BPF harmonic frequency rises.

- "FATAL ERRORS" will cause the program to automatically end execution. They suggest a drastic problem with the input to one of the Bessel function subroutines. It may also indicate that the matrix inversion routine (LINPACK) has detected a singular matrix. This type of error also occurs when certain dimension statements are violated (e.g. more modes than the system can handle). Under these circumstances the responsible program engineer and programmer should be contacted promptly to correct the problem.
- Errors stating that the number of radial or chordwise integration stations is not sufficient may indicate a loss in code accuracy for the BPF harmonic given. Experience has found that chordwise integration station errors on the rotor tend to be less serious than errors on the stator.

5.5 RUNNING THE CODE

To run SOURCE3D:

1. Insure that the source3d executable located in the "TFaNS1.5/bin" subdirectory has been sourced.
2. Enter source3d on the command line in the directory where you have an input file. At this point the following message will occur:

   "The input file must be on your current directory"
   "Enter the filename or carrage return (control d) to quit"

3. Enter the file name and press enter

5.6 SAMPLE INPUT

5.6.1 Sample test case when IWAKE > 0

Sample Input – This is an example of a two case input file. The first case corresponds to the test case in the "TFaNS1.5/source3d.v2.6/testcases/full.coupling" subdirectory. Note that since the second case is simply at a different operating condition, the rig geometry is not repeated. Only performance parameters are changed.

```
SAMPLE TEST CASE TITLE
&INPUT
ISTAGE=1, IPRED=1, ICASE=  2, IPRINT=0,
NDATS= 15, NHT= 3,
IWAKE=1, ISHAPE=3, EPSIL=3.0,
NBLADE= 18, NVANES= 45,
DDUCT= 22.0000,
XROT=  -1.096,      XROT1=  -1.250,      XROT2=   4.017,
XSTAT=   6.592,   XSTAT1=   4.017,   XSTAT2=   8.230,
RSWR= 10.156, RSWS= 10.156,
RADIUS=
       5.3708,  5.4625,  5.5921,  5.9304,  6.4439,  6.9207,
       7.3684,  7.9475,  8.5449,  9.1093,  9.6770, 10.0204,
      10.3558, 10.6832, 11.0000,
BROTOR=
       2.8216,  2.8504,  2.8891,  2.9902,  3.1102,  3.2077,
       3.2987,  3.4127,  3.5327,  3.6457,  3.7539,  3.8160,
       3.8740,  3.9329,  3.9896,
ALPHCHR=
        65.18,  65.16,  65.11,  64.98,  64.01,  62.48,
        60.56,  56.97,  53.13,  49.83,  46.60,  44.46,
        41.85,  38.71,  35.30,
YRD=
       0.0910,  0.1009,  0.1144,  0.1497,  0.1855,  0.1944,
       0.1867,  0.1251,  0.0435, -0.0307, -0.1043, -0.1533,
      -0.2123, -0.2841, -0.3581,
YRLED=
       -0.0140, -0.0155, -0.0176, -0.0231, -0.0407, -0.0629,
       -0.0958, -0.1481, -0.1970, -0.2341, -0.2670, -0.2895,
       -0.3201, -0.3608, -0.4007,
XRLED=
       0.0000,  0.0124,  0.0292,  0.0729,  0.1199,  0.1525,
       0.1731,  0.1668,  0.1487,  0.1250,  0.0955,  0.0689,
       0.0254, -0.0362, -0.1091,
XSPAC=
       5.1493,  5.1357,  5.1168,  5.0725,  5.0325,  4.9987,
       4.9834,  4.9672,  4.9577,  4.9565,  4.9566,  4.9768,
       4.9983,  5.0509,  5.1100,
BSTATR=
       1.6751,  1.6751,  1.6751,  1.6751,  1.6751,  1.6751,
       1.6751,  1.6751,  1.6751,  1.6751,  1.6751,  1.6751,
       1.6751,  1.6751,  1.6751,
```

```
ALPHCH=
        48.33,  49.39,  50.61,  52.96,  55.43,  57.13,
        58.46,  59.92,  61.15,  62.11,  62.87,  63.24,
        62.74,  60.36,  54.83,
YSD=
       0.0000, -0.0244, -0.0541, -0.1176, -0.1940, -0.2534,
      -0.3038, -0.3642, -0.4219, -0.4729, -0.5211, -0.5491,
      -0.5651, -0.5566, -0.5119,
XSD=
       0.0000,  0.0165,  0.0342,  0.0636,  0.0890,  0.1048,
       0.1159,  0.1266,  0.1344,  0.1396,  0.1431,  0.1444,
       0.1415,  0.1285,  0.0936,
N1C=   5424.0,
T01= 518.70, TAMB= 518.70, PAMB=2116.00,
TSI= 508.61, RHOI= 0.0728, MAI= 0.3095,
TSR= 519.49, RHOR= 0.0763, MAR= 0.3034,
TSS= 521.83, RHOS= 0.0772, MAS= 0.2753,
TSE= 524.01, RHOE= 0.0778, MAE= 0.3028,
MRSWR= 0.3571,ALPHASWR=  60.97,
MRSWS= 0.3307,ALPHASWS=  59.80,
MX=
       0.3201, 0.3199, 0.3198, 0.3197, 0.3198, 0.3194,
       0.3181, 0.3153, 0.3110, 0.3062, 0.3002, 0.2963,
       0.2929, 0.2913, 0.2951,
MRABSR=
       0.3503, 0.3517, 0.3539, 0.3603, 0.3694, 0.3783,
       0.3874, 0.4006, 0.4159, 0.4320, 0.4496, 0.4607,
       0.4690, 0.4709, 0.4627,
BETA1D=
        54.29, 53.81, 53.16, 51.52, 49.19, 47.12,
        45.21, 42.78, 40.35, 38.12, 35.92, 34.63,
        33.44, 32.48, 32.05,
BETA2D=
        72.07, 72.42, 72.93, 73.87, 74.56, 73.91,
        71.57, 66.94, 62.21, 58.21, 54.30, 51.86,
        48.88, 45.25, 41.23,
OMEGA=
       0.0494, 0.0445, 0.0377, 0.0206, 0.0142, 0.0136,
       0.0137, 0.0145, 0.0157, 0.0167, 0.0173, 0.0200,
       0.0451, 0.1164, 0.2510,
MRABS=
       0.2097, 0.2261, 0.2462, 0.2864, 0.3271, 0.3511,
       0.3619, 0.3647, 0.3630, 0.3587, 0.3497, 0.3399,
       0.3206, 0.2887, 0.2455,
ACLS= 59.05, 61.02, 63.04, 66.11, 68.18, 68.21,
        66.39, 62.56, 58.46, 54.68, 50.56, 47.65,
        43.77, 38.30, 29.52,
&END
&INPUT
N1C=   5901.0,
T01= 518.70, TAMB= 518.70, PAMB=2116.00,
```

```
TSI= 506.59, RHOI= 0.0721, MAI= 0.3376,
TSR= 520.16, RHOR= 0.0765, MAR= 0.3252,
TSS= 522.94, RHOS= 0.0775, MAS= 0.2946,
TSE= 525.81, RHOE= 0.0783, MAE= 0.3229,
MRSWR= 0.3865,ALPHASWR=  60.33,
MRSWS= 0.3586,ALPHASWS=  59.17,
MX=  0.3484, 0.3482, 0.3481, 0.3482, 0.3485, 0.3482,
.
.
.
&END
```

5.6.2 Sample test case when IWAKE = 0

Sample Input – This is an example of a case where IWAKE = 0. This case corresponds to the test case in the "TFaNS1.5/source3d.v2.6/testcases/from.awaken" subdirectory. This input file was actually generated using the AWAKEN code (See Section 8.).

```
Sample Test Case – AWAKEN output with measured data input
&INPUT
ISTAGE=  1, IPRED=  1, ICASE=  1, IPRINT=  0,
NDATS= 15, NHT= 3,
IWAKE=0, EPSIL=   3.000,
NBLADE= 18, NVANES= 45,
DDUCT= 22.0000,
XROT=  -1.098,      XROT1=  -1.250,      XROT2=   4.020,
XSTAT=   6.592,  XSTAT1=   4.020,   XSTAT2=   8.229,
RSWR= 10.159, RSWS= 10.159,
RADIUS=
       5.3933,  5.4854,  5.6153,  5.9545,  6.4688,  6.9457,
       7.3931,  7.9711,  8.5663,  9.1277,  9.6913, 10.0316,
      10.3636, 10.6870, 11.0000,
BROTOR=
       2.8296,  2.8572,  2.8961,  2.9974,  3.1159,  3.2128,
       3.3037,  3.4174,  3.5371,  3.6493,  3.7566,  3.8180,
       3.8753,  3.9336,  3.9896,
ALPHCHR=
        65.18,  65.15,  65.10,  64.97,  63.97,  62.40,
        60.46,  56.81,  53.00,  49.72,  46.52,  44.39,
        41.79,  38.67,  35.30,
YRD=
       0.0936,  0.1033,  0.1168,  0.1523,  0.1872,  0.1948,
       0.1862,  0.1219,  0.0406, -0.0331, -0.1061, -0.1549,
      -0.2137, -0.2850, -0.3581,
YRLED=
      -0.0144, -0.0159, -0.0180, -0.0235, -0.0416, -0.0641,
      -0.0977, -0.1501, -0.1987, -0.2351, -0.2678, -0.2902,
      -0.3208, -0.3613, -0.4007,
XRLED=
       0.0000,  0.0119,  0.0287,  0.0725,  0.1187,  0.1507,
       0.1708,  0.1628,  0.1444,  0.1207,  0.0913,  0.0646,
       0.0209, -0.0404, -0.1125,
```

```
XSPAC=
       5.1441,  5.1304,  5.1112,  5.0689,  5.0290,  4.9968,
       4.9818,  4.9664,  4.9570,  4.9565,  4.9570,  4.9781,
       4.9989,  5.0520,  5.1100,
BSTATR=
       1.6751,  1.6751,  1.6751,  1.6751,  1.6751,  1.6751,
       1.6751,  1.6751,  1.6751,  1.6751,  1.6751,  1.6751,
       1.6751,  1.6751,  1.6751,
ALPHCH=
        48.33,  49.46,  50.73,  53.14,  55.62,  57.32,
        58.63,  60.05,  61.26,  62.18,  62.91,  63.22,
        62.66,  60.27,  54.83,
YSD=
       0.0000, -0.0260, -0.0574, -0.1231, -0.2007, -0.2604,
      -0.3107, -0.3706, -0.4274, -0.4774, -0.5244, -0.5509,
      -0.5656, -0.5562, -0.5119,
XSD=
       0.0000,  0.0176,  0.0358,  0.0654,  0.0908,  0.1064,
       0.1171,  0.1275,  0.1350,  0.1400,  0.1432,  0.1442,
       0.1410,  0.1279,  0.0936,
N1C=   8749.8,
T01= 518.70, TAMB= 518.70, PAMB=2116.00,
TSI= 492.69, RHOI= 0.0673, MAI= 0.5130,
TSR= 525.87, RHOR= 0.0781, MAR= 0.4469,
TSS= 531.77, RHOS= 0.0803, MAS= 0.3996,
TSE= 539.99, RHOE= 0.0829, MAE= 0.4285,
MRSWR= 0.5592,ALPHASWR=  56.04,
MRSWS= 0.5229,ALPHASWS=  54.91,
MX=
       0.5216, 0.5216, 0.5219, 0.5233, 0.5255, 0.5266,
       0.5260, 0.5229, 0.5172, 0.5103, 0.5015, 0.4958,
       0.4911, 0.4897, 0.4971,
MRABSR=
       0.5471, 0.5495, 0.5532, 0.5638, 0.5789, 0.5937,
       0.6086, 0.6300, 0.6547, 0.6804, 0.7086, 0.7264,
       0.7401, 0.7450, 0.7365,
BETA1D=
        54.02, 53.56, 52.93, 51.37, 49.15, 47.19,
        45.37, 43.05, 40.71, 38.56, 36.44, 35.21,
        34.09, 33.21, 32.83,
BETA2D=
        71.92, 72.32, 72.89, 73.85, 74.44, 73.57,
        71.11, 66.53, 61.98, 58.17, 54.47, 52.12,
        49.20, 45.73, 41.72,
OMEGA=
       0.0471, 0.0425, 0.0361, 0.0213, 0.0162, 0.0159,
       0.0162, 0.0167, 0.0174, 0.0181, 0.0182, 0.0206,
       0.0442, 0.1087, 0.2278,
MRABS=
       0.3180, 0.3391, 0.3665, 0.4248, 0.4882, 0.5277,
       0.5479, 0.5568, 0.5589, 0.5568, 0.5469, 0.5341,
```

```
      0.5071, 0.4625, 0.4019,
 ACLS=
       56.50, 58.50, 60.62, 63.87, 66.22, 66.47,
       64.94, 61.46, 57.77, 54.38, 50.58, 47.83,
       44.07, 38.79, 30.14,
 NWAKE=  32
 PCTWAKE=
      0.00000,  0.03642,  0.06467,  0.08558,  0.12574,  0.16192,
      0.20375,  0.24559,  0.28345,  0.32360,  0.36314,  0.40330,
      0.44345,  0.48299,  0.52314,  0.56269,  0.60284,  0.63902,
      0.68253,  0.72269,  0.76055,  0.80238,  0.82162,  0.84254,
      0.86177,  0.88040,  0.90132,  0.92055,  0.94147,  0.96238,
      0.98101,  1.00000,
WAKHRM1=
      (-0.00059,-0.01591),(-0.01340,-0.00860),(-0.01763,0.00692),
      (-0.01569,0.01691),(0.00395,0.03170),(0.03653,0.02157),
      (0.04648,-0.01757),(0.02508,-0.03757),(0.00413,-0.03496),
      (-0.00773,-0.02287),(-0.01074,-0.01150),(-0.00961,-0.00585),
      (-0.00783,-0.00428),(-0.00625,-0.00567),(-0.00326,-0.00683),
      (0.00048,-0.00722),(0.00411,-0.00683),(0.00672,-0.00549),
      (0.00845,-0.00280),(0.00987,0.00009),(0.01040,0.00348),
      (0.01077,0.00685),(0.01168,0.00821),(0.01355,0.00935),
      (0.01646,0.01061),(0.01749,0.01252),(0.01838,0.01362),
      (0.01726,0.01174),(0.01580,0.00805),(0.01213,0.00446),
      (0.00805,0.00158),(0.00459,0.00680),
 WAKHRM2=
      (0.00284,-0.00119),(-0.00210,-0.00225),(-0.00282,0.00279),
      (0.00075,0.00359),(0.00036,-0.00184),(-0.00691,0.00459),
      (0.00662,0.01207),(0.01498,0.00004),(0.01110,-0.00905),
      (0.00139,-0.01164),(-0.00484,-0.00834),(-0.00513,-0.00606),
      (-0.00274,-0.00557),(0.00150,-0.00525),(0.00466,-0.00113),
      (0.00386,0.00349),(0.00026,0.00617),(-0.00358,0.00568),
      (-0.00636,0.00204),(-0.00670,-0.00224),(-0.00432,-0.00619),
      (-0.00033,-0.00711),(0.00135,-0.00575),(0.00155,-0.00298),
      (0.00065,-0.00054),(-0.00095,0.00128),(-0.00382,0.00153),
      (-0.00426,0.00091),(-0.00272,-0.00087),(-0.00117,-0.00203),
      (0.00138,-0.00159),(0.00160,0.00138),
 WAKHRM3=
      (0.00049,0.00052),(-0.00035,-0.00062),(-0.00088,0.00027),
      (0.00010,0.00050),(0.00172,-0.00072),(-0.00051,-0.00389),
      (-0.00221,0.00451),(0.00590,0.00353),(0.00503,-0.00252),
      (0.00060,-0.00547),(-0.00248,-0.00540),(-0.00177,-0.00495),
      (0.00114,-0.00424),(0.00369,-0.00070),(0.00075,0.00308),
      (-0.00319,0.00104),(-0.00291,-0.00303),(0.00059,-0.00458),
      (0.00419,-0.00159),(0.00390,0.00255),(0.00007,0.00464),
      (-0.00380,0.00222),(-0.00386,-0.00015),(-0.00247,-0.00258),
      (-0.00009,-0.00318),(0.00137,-0.00216),(0.00177,0.00007),
      (0.00022,0.00094),(-0.00041,0.00120),(-0.00121,0.00040),
      (-0.00061,-0.00044),(0.00074,-0.00012),
 &END
```

6. EVERSMAN INLET RADIATION CODE

6.1 GENERAL ORGANIZATION OF THE INLET RADIATION CODE

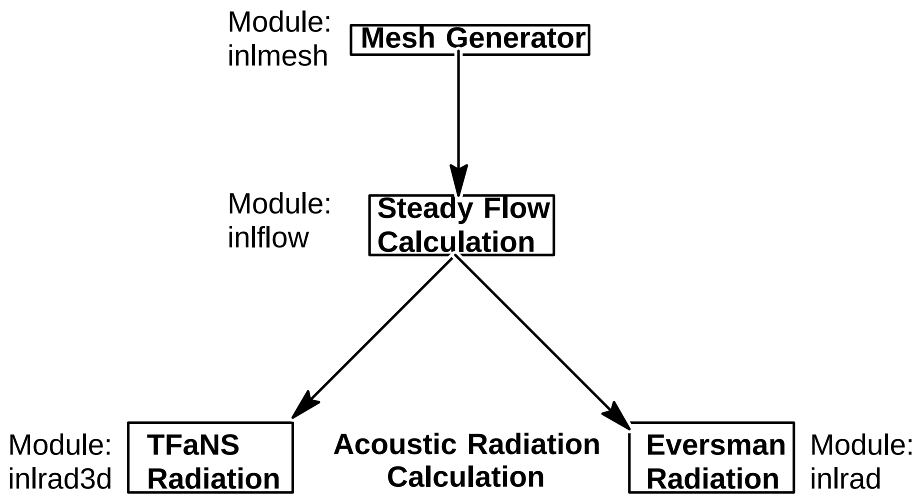


Figure 11: General Organization of the Inlet Radiation Code

Figure 11 shows the general organization of the inlet radiation code. The code is composed of a number of modules which are run in sequence by the user. These modules can be grouped into three main parts (see Figure 11):

1. Mesh Generator (see Section 6.2)

2. Steady Flow Calculation (see Sections 6.3)

3. Acoustic Radiation Calculation (see Sections 6.4 and 6.5)

Acoustic radiation can be calculated in one of two ways:

a. *Eversman Radiation:* In this case the code is not being run as a part of TFaNS. The code is run one circumferential mode order (for multiple radial mode orders) at a time.

b. *TFaNS Radiation:* In this case the code is being run as part of TFaNS. This case will output the Acoustic Properties File needed for CUP3D.

The parts of the code will now be discussed in further detail with reference to Figure 11:

Mesh Generator

The "inlmesh" module (see Figure 11) generates the computational finite element mesh for the nacelle inlet of interest. It may also calculate acoustic mode information which is used by the Eversman radiation module. This information is output to a file to be used by all other modules. See Section 6.2 for more information.

Steady Flow Calculation

The “inlflow” module calculates two steady potential flow solutions for the computational domain. A file is output for use by the radiation modules. See Section 6.3 for more information.

Acoustic Radiation Calculation

The radiation calculation performs the following calculations:

- It combines the two potential flow solutions with mean axial Mach numbers at the input plane and in the far−field. This forms the steady flow for the radiation calculation.
- It may calculate the mode eigenfunctions required for the radiation calculation (if not computed in “inlmesh”)
- It calculates the far−field directivities for a given frequency and mode input.

This calculation can take on two forms:

A. Eversman Radiation

If the radiation code (“inlrad”) is being run independently of TFaNS, then this option may be used to calculate far−field directivities given mode amplitudes for a circumferential mode order, m. Far−field directivities non−dimensionalized by $\rho_\infty c_\infty^2$ are output where ρ_∞ is the static density in the far−field and c_∞ is the static acoustic speed in the far field. Note that “inlrad” places temporary work files on the user’s workstation while the code is running.

See Section 6.4 for more information.

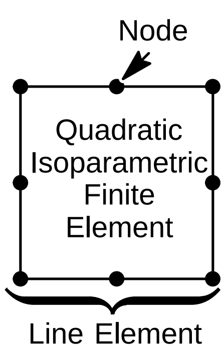
B. TFaNS Radiation

If the radiation code (“inlrad3d”) is being run as a part of TFaNS, then this option should be used to create an acoustic properties file. Note that “inlrad3d” places temporary work files on the user’s workstation while the code is running.

See Section 6.5 for more information.

Terms Utilized by This Section

There are terms utilized by this section which are explained briefly below:



Computational Mesh: Grid of finite elements needed to find the solution.

Finite Element: A finite sub–domain in which the solution is approximated. The number of elements per wavelength will affect the solution (see Section 6.2.3).

Node: Points where the equations of motion are discretized. The code also uses “shape functions” which determine how to interpolate the solution within each element for specified values of the solution at the nodes. There are eight nodes per element in this code.

Line Element: Entire length of one side of an element. This term is used to describe the surfaces on the nacelle and centerbody.

The technical documentation for the inlet radiation code may be found in References 5 to 9.

9

6.2 MESH GENERATOR

6.2.1 Input Format

The finite element mesh generation code "inlmesh" generates the finite element mesh for the computation of the far field radiation from an engine fan inlet. The program is dimensioned using parameter statements. The input data file structure has distinct blocks of input data referred to as cards. Each card begins on a new line and the input data on the card is generally formatted. The data format determines the maximum line length. If there is more data than can fit on one line, a card is continued on additional lines. The input variables should be input in the file in the sequence given.

There are three regions of the computational domain described in the input data (See Figure 12). Region I is within the duct bounded by the highlight circle. The number of elements axially in this region is determined by the number of line elements on the inner duct surface. Region II is outside the highlight circle and nacelle and extends to the wave envelope elements. The wave envelope elements are in Region III. While grid is generated for Region III, the radiation modules use infinite finite elements in the far−field now. Thus, the wave envelop elements are no longer used (see Reference 9). The centerbody must be within the highlight circle. This allows a modest protrusion of the centerbody beyond the inlet tip (15% to 20% of the inlet radius).

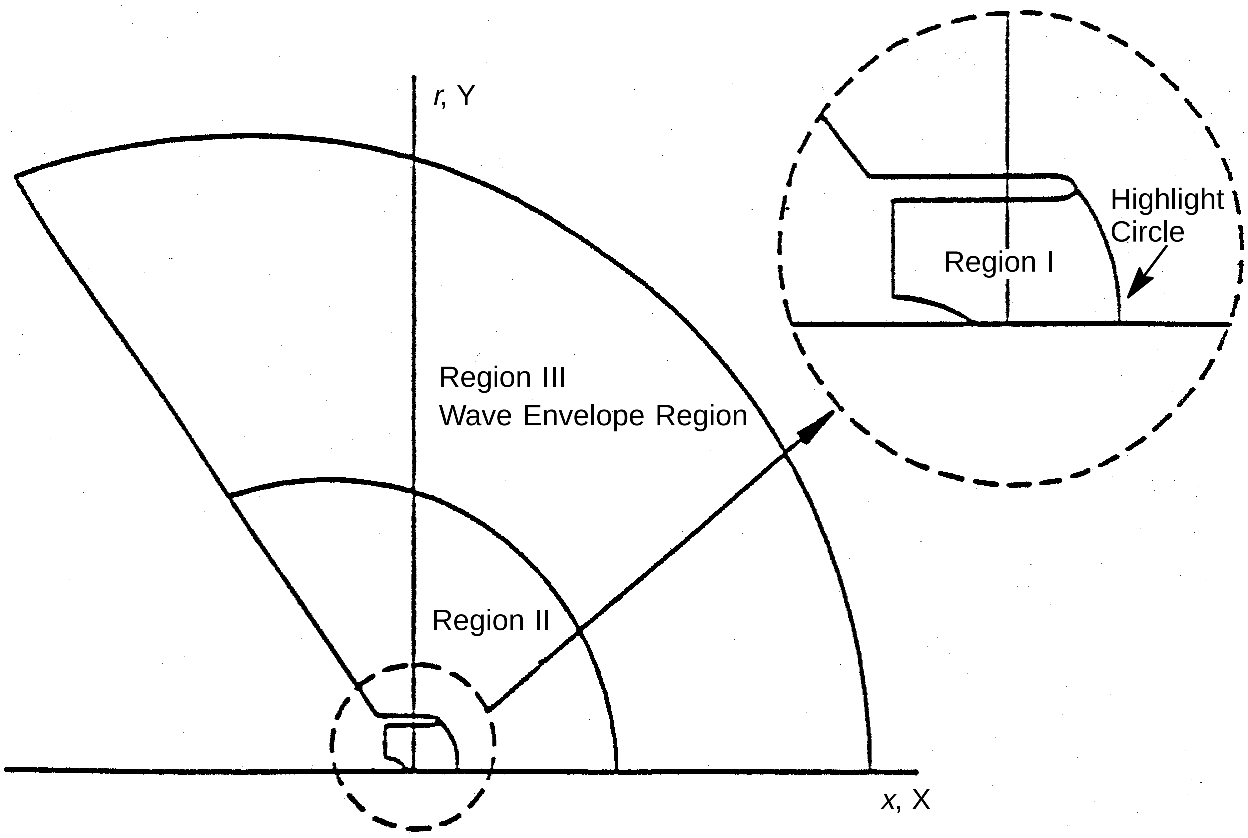


Figure 12: Inlet computational domain showing the boundaries and regions

The mesh generator calculates the mesh in two parts. The first part of the program uses a spline curve fit procedure for the inlet fan duct and centerbody geometry. For this part the user must supply

enough x and r coordinates (also called X and Y coordinates in the code) to define the shape of the outer nacelle, the inner duct, and the centerbody. Using the spline information, the surfaces of the nacelle are discretized into line elements whose end points are defined. The center node of the elements is created from the knowledge of the end points. The curve fit is a natural cubic spline. The second part generates the mesh using a mesh generation scheme for the spline fitted nacelle.

There are two options for running the mesh generator:

Option	**Option 1**	**Option 2**
What it runs	Runs both parts of the code: 1) Spline fits the nacelle boundaries and centerbody 2) Generates the mesh	Runs the second part of the code only to generate the mesh based on boundary element definitions given by the user.
Input file	INLPRE.INP	INLMESH.INP
Best time to use	Used when: 1) Starting from scratch with a nacelle 2) When altering the mesh resolution on the nacelle boundaries.	INLMESH.INP would have typically been generated in a prior run using Option 1. Could be used when: 1) Changing things not associated with the nacelle geometry. 2) Modifying boundary elements from those generated by the spline fit.

Mode (eigenvalue/eigenvector) information for either option can either be calculated in the mesh generator or radiation module:

To calculate mode eigenvalues/eigenfunctions in:	Mesh generator ("inlmesh")	Radiation module
In the mesh generator set NPOS equal to:	No. of radial mode orders being run	0 (zero)
Best time to use	Useful if user has a special application	1) User is running the TFaNS version of the radiation code, "inlrad3d". 2) User would like to run mode calculations in standard Eversman radiation module

Figure 13 and Figure 14 can be consulted for details of the computational region which are relevant to the mesh generation.

6.2.1.1 Input Running Option 1: Spline Fit Nacelle Boundaries, Calculate Mesh.

The input plane, shown in Figure 13, refers to the radial plane in the duct (at an axial location) where the noise is input in terms of modal amplitudes.

The first card is a header card allowing a maximum of 72 characters. It is formatted (18A4). It is not counted in the card sequence numbers defined below.

The input is a combination of formatted and free format data. Each card of data begins on a new line.

All lengths are non−dimensionalized by the outer duct radius at the input plane.

Card	Variable	Format	Description
1	NELU	Free Format	Number of line elements describing the upper surface of the nacelle (NLINU in Option 2). Establishes near field finite element (FEM) mesh density (Figure 13). *Note:* Number of points (nodes) on the upper nacelle surface is NELU + 1.
	NELI	Free Format	Number of line elements describing the inner surface; also number of elements on the centerbody and centerline between the input plane & the highlight circle (NLINLI in Option 2). Establishes near field FEM mesh density (Figure 13). *Note:* Number of points (nodes) on the inner nacelle surface is NELI + 1.
2	XBAF	Free Format	x−coordinate of the intersection of the baffle with the upper surface of the nacelle (Figure 14)
	XTIP	Free Format	x−coordinate of the nacelle highlight (Figure 14)
	YTIP	Free Format	r−coordinate of the nacelle highlight (Figure 14)
	XFAN	Free Format	x−coordinate of the input plane (Figure 14)
	XCB	Free Format	x−coordinate of the leading edge of the centerbody (Figure 14)
3	FRACTU(I)	Free Format	I=1, NELU + 1; Fraction of arc length between baffle and highlight circle where element end points will be placed on the upper surface of the nacelle (includes zero) (Figure 14)
4	FRACTI(I)	Free Format	I=1, NELI + 1; Fraction of arc length between input plane and highlight where element end points will be placed on the nacelle inner surface (includes zero) (Figure 14) *Note:* The inner centerbody is segmented as the inner nacelle surface.
5	NUPPER	Free Format	Number of intervals for upper nacelle surface spline (no. of points on the upper nacelle surface is NUPPER + 1) (Figure 13).
6	X(I) & Y(I)	Free Format	I=1, NUPPER + 1; Nacelle upper surface (x, r) coordinate pairs for spline fit; each coordinate pair should be input on a new line, i.e., there are NUPPER + 1 lines corresponding to this card block − each line representing a coordinate pair (Figure 14).
7	NINNER	Free Format	Number of intervals for inner nacelle surface spline (no. of points on the inner nacelle surface is NINNER + 1) (Figure 13)
8	X(I) & Y(I)	Free Format	I=1, NINNER + 1; Nacelle inner surface (x ,r) coordinate pairs for spline fit; each coordinate pair should be input on a new line, i.e., there are NINNER+1 lines corresponding to this card block − each line representing a coordinate pair (Figure 14).
9	NELCEN	Free Format	Number of intervals for spline for entire centerbody (no. of centerbody points is NELCEN + 1) centerbody only, does not include centerline (Figure 13).

10	X(I) & Y(I)	Free Format	I=1, NELCEN + 1; Centerbody (*x, r*) coordinate pairs for spline fit; each coordinate pair should be input on a new line, i.e., there are NELCEN+1 lines corresponding to this card block − each line representing a coordinate pair (Figure 14). *Note:* The number of (*x, r*) coordinate pairs for the centerbody does not include points on the centerline.
11	NY	I5	Number of elements along the duct radius in Region I (This is equal to the number of three−node line elements on the input plane). The input plane is the plane, x = constant, at which the input duct modal amplitudes are specified (Figure 13).
	NX2	I5	Number of elements radially in Region II (Figure 13).
	NWEEL	I5	Number of wave envelope elements (Figure 13).
	NPRINT	I5	=0, do not print nodal coordinate array =1, print nodal coordinate array
	NDONT	I5	=0, do not write output data file =1, write output data file
	NCNTR	I5	= 0, there is no centerbody = 1, there is a centerbody
12	PCNT(I)	6F10.0	I = 1, NY; end node locations of the three−node line elements lying along the input plane. The node locations are given as fractions of the input plane width and starting from the intersection of the input plane and the lower surface of the nacelle. The first node therefore has a zero fractional distance and is not an input. If there are 5 line elements along the input plane then a typical input for this array would be 0.2, 0.4, 0.65, 0.88, 1.00 (Figure 14)
13	R2	F10.0	Outer radius of Region II in multiples of input plane duct radius (Figure 14)
14	R3, R4, etc.	6F10.0	Outer radii of the successive layers of wave envelope elements in multiples of input plane duct radius. There are NWEEL of these. Three to eight layers is usually sufficient.
15	MT	I5	Circumferential mode order (angular mode number), m
	NPOS	I5	No. of radial mode orders for circumferential mode order, m. Set NPOS=0 to skip the mode calculation. Do this if: 1) TFaNS version of radiation module is being run, or 2) Doing the radial mode order calculations in the Eversman Radiation Module is desired.
	VMACH	F10.0	Exterior flow Mach number (Positive for forward flight effect)
15	MSHIFT	I10	=0, no shift of the nacelle geometry left or right =1, shift of the nacelle geometry left or right
	XSHIFT	F10.0	Shift the nacelle geometry to help center the near field radiation for better performance of the wave envelope elements. Positive value of XSHIFT means shift to the left, i.e. shift towards the inlet.

6.2.1.2 Input Running Option 2: Calculate Mesh only.

The first card is a header card allowing a maximum of 72 characters. It is formatted (18A4). It is not counted in the card sequence number defined below. Most of the data required in this option is also used in option 1.

All lengths are non−dimensionalized by the duct radius at the input plane.

Card	Variable	Format	Description
1	NLINU	I5	Number of three−node line elements to describe the upper surface of the nacelle
	NLINLI	I5	Number of three−node line elements to describe the lower surface of the nacelle
	NY	I5	Number of elements along the duct radius in Region I
	NX2	I5	Number of elements radially in Region II.
	NWEEL	I5	Number of wave envelope layers
	NPRINT	I5	= 0, do not write nodal coordinate array = 1, write nodal coordinate array
	NDONT	I5	= 0, do not write output data file = 1, write output data file
	NCNTR	I5	= 0, there is no centerbody = 1, there is a centerbody
	NCNTR1	I5	Sequence number of the first line element on the centerbody. It is the first element from the intersection of the centerbody and the input plane. Usually NCNTR1 = 1
	NCNTR2	I5	Sequence number of the last line element on the centerbody. It is the element at the intersection of the centerbody and the x−axis.
2	PCNT	6F10.0	I = 1, NY; Element end node locations from top to bottom in Region I. Fraction of region I width. The first node at zero is not input.
3	X(I),Y(I), I=1,3	6F10.0	Coordinates of the three nodes on a line defining the upper nacelle surface. One line per element. There will be duplication of end point values. Sequenced from baffle forward. (NLINU records)
4	X(I),Y(I), I=1,3	6F10.0	Coordinates of three nodes on a line defining the inner surface of the inlet. One line per element. There will be duplication of end point values. Sequenced from input plane forward. (NLINLI records)
5	X(I),Y(I), I=1,3	6F10.0	Coordinates of the three nodes on a line defining the centerbody. One line per element. There will be duplication of end point values. Centerbody coordinates are defined on the centerbody and on the centerline to intersection of highlight circle. (NLINLI records)
6	R2	F10.0	Outer radius of Region II in multiples of input plane duct radius
7	R3,R4,etc.	6F10.0	The outer radii of the successive layers of wave envelope elements in multiples of input plane duct radius. There are NWEEL of these. Three to eight layers is usually sufficient.

8	MT	I5	Circumferential mode order (angular mode number), *m*
	NPOS	I5	No. of radial mode orders for circumferential mode order, *m* (see remarks about NPOS in Option 1)
	VMACH	F10.0	Exterior flow Mach number (Positive for forward flight effect)
9	MSHIFT	I10	=0, No shift of the nacelle geometry left or right =1, Shift the nacelle geometry left or right
	XSHIFT	F10.0	Shift the nacelle geometry to help center the near field radiation for better performance of the wave envelope elements. Positive value of XSHIFT means shift to the left, i.e. shift towards the inlet.

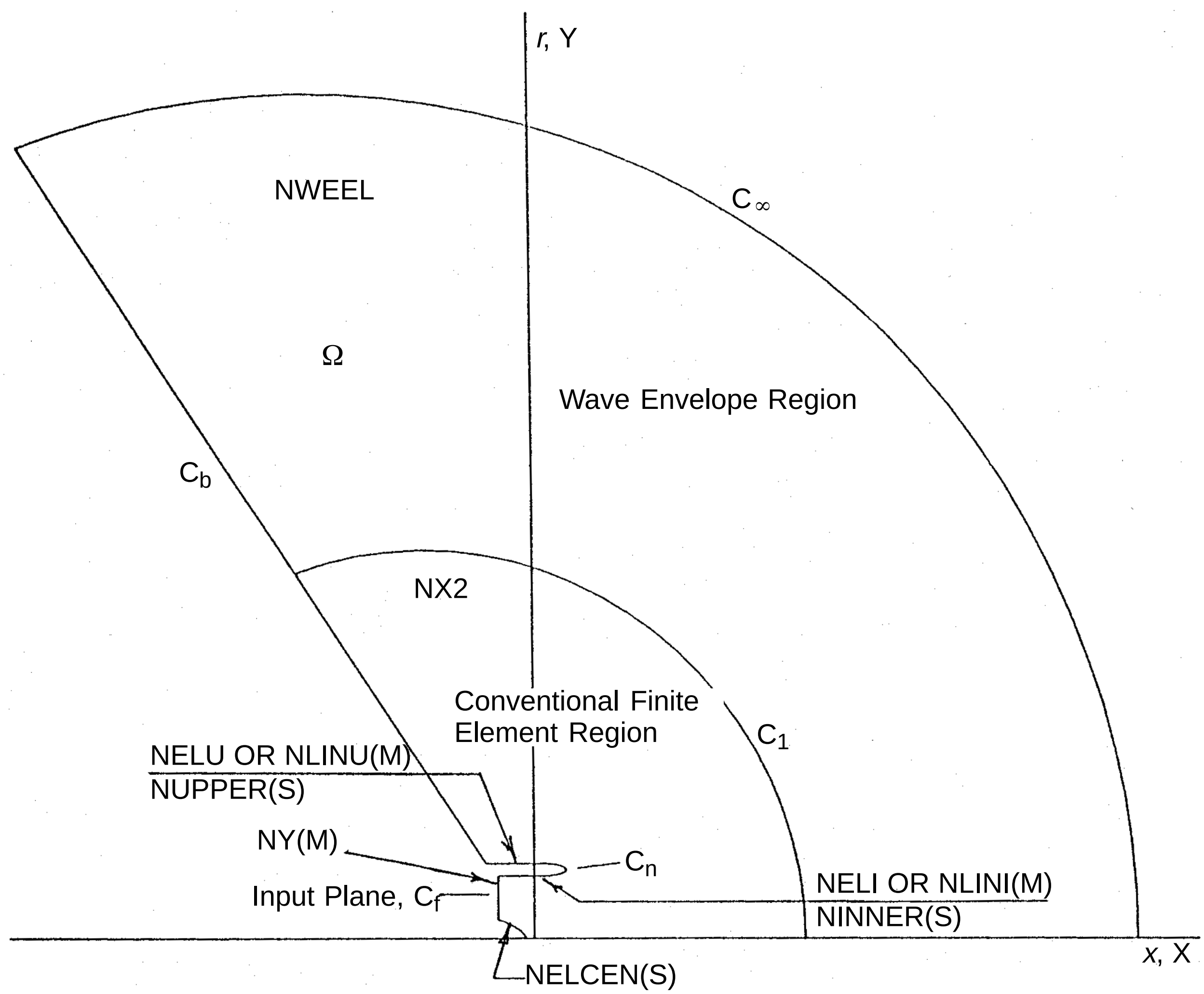


Figure 13: Inlet computational domain showing input data related to numbers of mesh line elements, M, and spline intervals, S, on the various boundaries

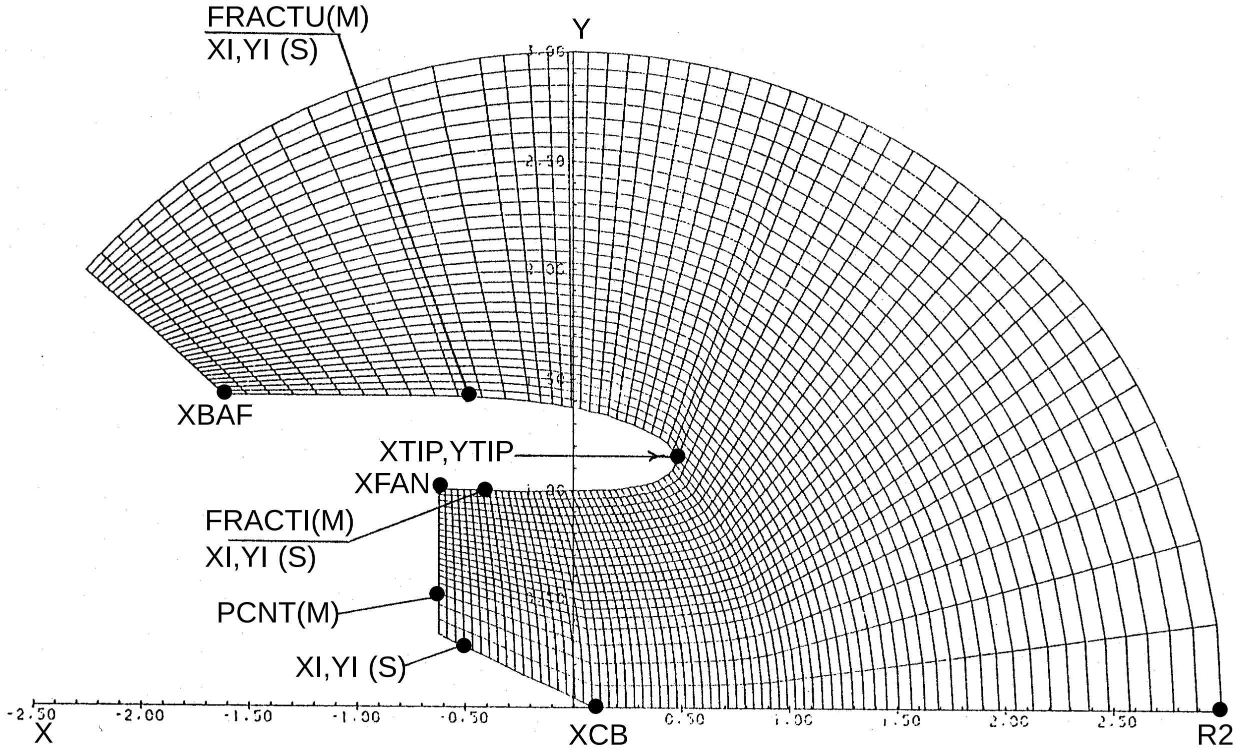


Figure 14: Inlet mesh example showing key geometry points mesh line element end points, M, and spline intervals, S, on the various boundaries

6.2.2 Output Files

The mesh generation code, “inlmesh”, outputs the following files:

Output File	Output File Name	When Created	What is in it?
General Output	INLMESH.OUT	Always	Spline fit results (if option 1 is run) List of element locations on each boundary Radiation element surface element topology and connectivity Total number of Elements and number of nodes
Mesh “restart” file	INLMESH.DAT	Always	The mesh file used by all other parts of the radiation code
Postscript plotting file	INLMESH.PS	Always	Mesh for the three regions split into three plots: • Region I only • Regions I and II • Regions II and III These plots can be used to inspect the mesh for problems.
Option 2 input file	INLMESH.INP	If option 1 is run	Input file which can be used to run option 2

6.2.3 Mesh Generation Hints

The general rule for the mesh density is that there should be about four to five elements per wave length in the principle direction of propagation in the regular mesh (within the duct, Region I, and in Region II). The principle direction of propagation is axial in the duct and radial outside the duct. the number of elements per unit length can be related to the number of elements per wave length (accounting for wave length shortening due to local convection) by the formula:

$$N_\lambda = \frac{2\pi}{\eta_r}(1 - M)N_R \qquad (4)$$

or

$$N_R = \frac{\eta_r}{2\pi(1 - M)}N_\lambda \qquad (5)$$

where:

N_λ = *number of elements per wave length*
N_R = *number of elements per unit length (a unit length is one input plane outer radius)*
η_r = *non dimensional frequency based on the reference speed of sound and the input plane outer radius.*
M = *local Mach number in flow which is positive downstream. the conservative choice for this would be the largest Mach number in the inlet.*

For a required N_λ, this can be used to determine N_R. a good goal for N_λ is 4 to 5.

The mesh density across the duct and in the angular direction outside the duct should ideally be based on the same requirement, however results suggest that a much more coarse discretization provides reasonable results, and a good rule is to try to keep the element aspect ratio near 2.

For cases where the propagation is principally to the sideline (i.e., for nearly cut−off or cut−off modes) there can be significant reflection from the baffle. in these cases consideration should be given to sweeping the baffle back as far as possible consistent with computational size constraints.

6.2.4 Sample Input

6.2.4.1 Option 1: INLPRE.INP

This sample mesh generation module input file for option 1 comes from the inlet radiation code's "TFaNS1.5/inlrad.v4.0/testcases" subdirectory.

```
Sample input file
  44 100
   -1.20809 1.15323 1.01561 0.11364 0.70374
    0.0D0   0.04D0  0.08D0  0.12D0  0.16D0   0.19D0  0.22D0  0.25D0
    0.28D0  0.30D0  0.32D0  0.34D0  0.36D0   0.38D0  0.40D0  0.42D0
    0.44D0  0.46D0  0.48D0  0.50D0  0.52D0   0.54D0  0.56D0  0.58D0
    0.60D0  0.62D0  0.64D0  0.66D0  0.68D0   0.70D0  0.72D0  0.74D0
    0.76D0  0.78D0  0.80D0  0.82D0  0.84D0   0.86D0  0.88D0  0.90D0
    0.92D0  0.94D0  0.96D0  0.98D0   1.0D0
    0.000D0 0.010D0 0.020D0 0.030D0 0.040D0 0.050D0  0.060D0 0.070D0
    0.080D0 0.090D0 0.100D0 0.110D0 0.120D0 0.130D0  0.140D0 0.150D0
    0.160D0 0.170D0 0.180D0 0.190D0 0.200D0 0.210D0  0.220D0 0.230D0
    0.240D0 0.250D0 0.260D0 0.270D0 0.280D0 0.290D0  0.300D0 0.310D0
    0.320D0 0.330D0 0.340D0 0.350D0 0.360D0 0.370D0  0.380D0 0.390D0
    0.400D0 0.410D0 0.420D0 0.430D0 0.440D0 0.450D0  0.460D0 0.470D0
    0.480D0 0.490D0 0.500D0 0.510D0 0.520D0 0.530D0  0.540D0 0.550D0
    0.560D0 0.570D0 0.580D0 0.590D0 0.600D0 0.610D0  0.620D0 0.630D0
    0.640D0 0.650D0 0.660D0 0.670D0 0.680D0 0.690D0  0.700D0 0.710D0
    0.720D0 0.730D0 0.740D0 0.750D0 0.760D0 0.770D0  0.780D0 0.790D0
    0.800D0 0.810D0 0.820D0 0.830D0 0.840D0 0.850D0  0.860D0 0.870D0
    0.880D0 0.890D0 0.900D0 0.910D0 0.920D0 0.930D0  0.940D0 0.950D0
    0.960D0 0.970D0 0.980D0 0.990D0 1.000D0
   78
-1.96774         0.986522
-1.93126         0.995512
-1.89467          1.00432
-1.85797          1.01294
-1.82117          1.02137
-1.78426          1.02962
-1.74725          1.03768
-1.71014          1.04556
-1.67291          1.05326
-1.63558          1.06076
-1.59815          1.06808
-1.56061          1.07522
-1.52296          1.08217
-1.48521          1.08894
```

–1.44736	1.09552
–1.40940	1.10192
–1.37133	1.10812
–1.33315	1.11415
–1.29487	1.11999
–1.25649	1.12564
–1.21800	1.13111
–1.17940	1.13639
–1.14070	1.14149
–1.10189	1.14640
–1.06298	1.15113
–1.02396	1.15567
–.984839	1.16003
–.945609	1.16420
–.906273	1.16819
–.866832	1.17199
–.827286	1.17560
–.787633	1.17903
–.747875	1.18227
–.708012	1.18533
–.668043	1.18821
–.627967	1.19089
–.587788	1.19340
–.547501	1.19571
–.507110	1.19784
–.466613	1.19979
–.426009	1.20155
–.385301	1.20313
–.344487	1.20452
–.303567	1.20572
–.262541	1.20674
–.221411	1.20758
–.180173	1.20823
–.138831	1.20869
–.973837E–01	1.20897
–.558292E–01	1.20906
–.672558E–02	1.20882
0.446545E–01	1.20809
0.981673E–01	1.20681
0.153625	1.20497
0.210790	1.20251
0.269382	1.19944
0.329072	1.19571
0.389486	1.19133
0.450216	1.18628
0.510819	1.18059
0.570830	1.17426
0.629773	1.16733
0.687169	1.15983
0.742555	1.15182
0.795486	1.14335

0.845557	1.13449
0.892407	1.12531
0.935729	1.11588
0.975277	1.10627
1.01087	1.09658
1.04239	1.08686
1.06979	1.07719
1.09308	1.06764
1.11233	1.05827
1.12764	1.04912
1.13918	1.04025
1.14715	1.03169
1.15175	1.02347
1.15323	1.01561
153	
–1.96774	0.981976
–1.92372	0.989556
–1.88088	0.996573
–1.83920	1.00304
–1.79865	1.00899
–1.75921	1.01442
–1.72086	1.01937
–1.68357	1.02384
–1.64732	1.02786
–1.61208	1.03145
–1.57783	1.03462
–1.54454	1.03739
–1.51220	1.03978
–1.48077	1.04181
–1.45023	1.04350
–1.42056	1.04486
–1.39173	1.04592
–1.36372	1.04669
–1.33651	1.04719
–1.31006	1.04744
–1.28436	1.04746
–1.25938	1.04727
–1.23510	1.04688
–1.21149	1.04631
–1.18854	1.04558
–1.16620	1.04472
–1.14447	1.04373
–1.12331	1.04264
–1.10270	1.04146
–1.08262	1.04022
–1.06304	1.03893
–1.04394	1.03761
–1.02530	1.03628
–1.00709	1.03496
–.989277	1.03367
–.971850	1.03241

–.954781	1.03122
–.938044	1.03012
–.921616	1.02911
–.905473	1.02822
–.889589	1.02746
–.873941	1.02686
–.858505	1.02643
–.843256	1.02620
–.828169	1.02617
–.813223	1.02638
–.798342	1.02676
–.783467	1.02722
–.768593	1.02772
–.753715	1.02820
–.737201	1.02904
–.720716	1.03036
–.704245	1.03190
–.687769	1.03343
–.671274	1.03470
–.654761	1.03573
–.638236	1.03651
–.621704	1.03704
–.605167	1.03729
–.589072	1.03728
–.572977	1.03704
–.556883	1.03660
–.540790	1.03601
–.524705	1.03523
–.508639	1.03421
–.492603	1.03287
–.476607	1.03116
–.460647	1.02913
–.444714	1.02685
–.428798	1.02440
–.412892	1.02185
–.396986	1.01929
–.381074	1.01677
–.365151	1.01433
–.349215	1.01201
–.333265	1.00984
–.317298	1.00783
–.301312	1.00603
–.285305	1.00446
–.269278	1.00310
–.253231	1.00193
–.237168	1.00091
–.221090	1.00001
–.204997	0.999183
–.188893	0.998412
–.172784	0.997765
–.156685	0.997488

-.140613	0.997837
-.123033	0.998855
-.105510	1.00099
-.879962E-01	1.00307
-.704568E-01	1.00470
-.528674E-01	1.00577
-.352498E-01	1.00637
-.176267E-01	1.00663
0.	1.00673
0.176312E-01	1.00671
0.352443E-01	1.00624
0.528174E-01	1.00500
0.703686E-01	1.00333
0.915463E-01	1.00137
0.112756	1.00002
0.126737	0.999647
0.140725	0.999401
0.158341	0.998813
0.175939	0.997850
0.201030	0.996054
0.226121	0.993928
0.251212	0.991491
0.276303	0.988762
0.301394	0.985767
0.326484	0.982532
0.351575	0.979086
0.376665	0.975459
0.401756	0.971683
0.426846	0.967792
0.451936	0.963820
0.477026	0.959802
0.502116	0.955773
0.527206	0.951769
0.552296	0.947826
0.577386	0.943979
0.602476	0.940260
0.627567	0.936703
0.652657	0.933341
0.677747	0.930201
0.702839	0.927313
0.727929	0.924700
0.753021	0.922388
0.778111	0.920396
0.803203	0.918741
0.828294	0.917439
0.853384	0.916500
0.878476	0.915934
0.903566	0.915745
0.922413	0.916029
0.941690	0.916916
0.961228	0.918445

0.980839	0.920648
1.00031	0.923547
1.01941	0.927147
1.03792	0.931439
1.05561	0.936399
1.07224	0.941984
1.08763	0.948139
1.10160	0.954794
1.11399	0.961867
1.12473	0.969271
1.13373	0.976913
1.14097	0.984701
1.14648	0.992545
1.15030	1.00036
1.15252	1.00807
1.15323	1.01561
107	
–4.38645	0.314974
–4.29076	0.339761
–4.19020	0.354259
–4.09721	0.362395
–4.00423	0.370530
–3.91124	0.378665
–3.81825	0.386800
–3.71764	0.395603
–3.61703	0.404405
–3.51642	0.413208
–3.41581	0.422010
–3.25900	0.435728
–3.19963	0.439619
–3.14015	0.440917
–2.95053	0.440917
–2.76091	0.440917
–2.70143	0.439619
–2.64206	0.435728
–2.60482	0.432470
–2.54545	0.428579
–2.48596	0.427281
–2.43186	0.427281
–2.36368	0.427281
–2.30459	0.427281
–2.23186	0.427281
–2.16822	0.427281
–2.12277	0.427281
–2.07731	0.427281
–2.05288	0.427281
–2.04098	0.427021
–2.02911	0.426243
–1.94931	0.419262
–1.86952	0.412281
–1.85004	0.411371

-1.82406	0.409099
-1.77276	0.409099
-1.72731	0.409099
-1.63639	0.409099
-1.54548	0.409099
-1.45457	0.409099
-1.36366	0.409099
-1.27275	0.409099
-1.18184	0.409099
-1.09093	0.409099
-1.00002	0.409099
-.954564	0.409099
-.903267	0.409099
-.890279	0.410235
-.877289	0.411371
-.868198	0.411371
-.822175	0.415398
-.776149	0.419424
-.764276	0.420203
-.752380	0.420463
-.733014	0.420463
-.713651	0.420463
-.697000	0.419953
-.689426	0.419384
-.672739	0.417897
-.588037	0.410343
-.490918	0.401683
-.470009	0.400008
-.411826	0.400008
-.353643	0.410462
-.294552	0.430008
-.249550	0.443698
-.202731	0.452281
-.150084	0.453640
-.117004	0.452743
-.840234E-01	0.450090
-.625012E-01	0.446608
-.515201E-01	0.444016
-.195840E-01	0.435341
0.	0.430994
0.129248E-01	0.429382
0.459836E-01	0.428095
0.790715E-01	0.427530
0.100911	0.426372
0.158186	0.419644
0.187276	0.415826
0.244550	0.405644
0.301369	0.391917
0.357734	0.374371
0.413462	0.352461
0.495282	0.310188

```
0.510000          0.301960
0.520000          0.296159
0.530000          0.290050
0.540000          0.283516
0.550000          0.276439
0.560000          0.268701
0.570000          0.260183
0.580000          0.250769
0.590000          0.240340
0.599739          0.229095
0.610000          0.216044
0.620000          0.202392
0.630000          0.188142
0.640000          0.173616
0.650000          0.159133
0.660000          0.145014
0.670000          0.131580
0.673649          0.126912
0.680000          0.118391
0.690000          0.950636E-01
0.699104          0.503646E-01
0.702741          0.235459E-01
0.703741                0.
   33   32    9    0    1    1
 0.0300000 0.0600000 0.0900000 0.1200000 0.1500000 0.1800000
 0.2100000 0.2400000 0.2700000 0.3000000 0.3300000 0.3600000
 0.3900000 0.4200000 0.4500000 0.4800000 0.5100000 0.5400000
 0.5700000 0.6000000 0.6300000 0.6600000 0.6900000 0.7200000
 0.7500000 0.7800000 0.8100000 0.8400000 0.8700000 0.9000000
 0.9300000 0.9650000 1.0000000
 2.5000000
 2.7000000 2.9000000 3.5000000 4.3000000 5.0000000 6.0000000
 7.0000000 8.3000000 10.00240
   10    0 0.1
         1     0.50
```

6.2.4.2 Option 2: INLMESH.INP

This sample mesh generation module input file for option 2 was generated by the input file shown above for option 1.

```
Sample Input File – Option 2
   44  100   33   32    9    0    1    1    1   41
    0.03000   0.06000   0.09000   0.12000   0.15000   0.18000
    0.21000   0.24000   0.27000   0.30000   0.33000   0.36000
    0.39000   0.42000   0.45000   0.48000   0.51000   0.54000
    0.57000   0.60000   0.63000   0.66000   0.69000   0.72000
    0.75000   0.78000   0.81000   0.84000   0.87000   0.90000
    0.93000   0.96500   1.00000
   -1.20809   1.13248  -1.16052   1.13890  -1.11290   1.14503
   -1.11290   1.14503  -1.06525   1.15086  -1.01757   1.15640
```

−1.01757	1.15640	−0.96985	1.16165	−0.92210	1.16661
−0.92210	1.16661	−0.87432	1.17128	−0.82652	1.17567
−0.82652	1.17567	−0.79065	1.17878	−0.75477	1.18172
−0.75477	1.18172	−0.71887	1.18452	−0.68296	1.18716
−0.68296	1.18716	−0.64705	1.18964	−0.61112	1.19197
−0.61112	1.19197	−0.57518	1.19414	−0.53923	1.19616
−0.53923	1.19616	−0.51526	1.19743	−0.49129	1.19862
−0.49129	1.19862	−0.46731	1.19976	−0.44333	1.20082
−0.44333	1.20082	−0.41935	1.20182	−0.39537	1.20276
−0.39537	1.20276	−0.37138	1.20363	−0.34739	1.20443
−0.34739	1.20443	−0.32340	1.20516	−0.29941	1.20583
−0.29941	1.20583	−0.27541	1.20644	−0.25141	1.20699
−0.25141	1.20699	−0.22742	1.20747	−0.20342	1.20789
−0.20342	1.20789	−0.17942	1.20824	−0.15542	1.20853
−0.15542	1.20853	−0.13141	1.20875	−0.10741	1.20892
−0.10741	1.20892	−0.08341	1.20903	−0.05941	1.20906
−0.05941	1.20906	−0.03540	1.20901	−0.01140	1.20886
−0.01140	1.20886	0.01260	1.20860	0.03660	1.20824
0.03660	1.20824	0.06060	1.20776	0.08459	1.20718
0.08459	1.20718	0.10859	1.20650	0.13258	1.20573
0.13258	1.20573	0.15656	1.20486	0.18055	1.20388
0.18055	1.20388	0.20452	1.20281	0.22850	1.20164
0.22850	1.20164	0.25247	1.20039	0.27643	1.19903
0.27643	1.19903	0.30039	1.19758	0.32434	1.19603
0.32434	1.19603	0.34829	1.19438	0.37223	1.19264
0.37223	1.19264	0.39616	1.19081	0.42009	1.18887
0.42009	1.18887	0.44400	1.18683	0.46791	1.18469
0.46791	1.18469	0.49181	1.18245	0.51570	1.18010
0.51570	1.18010	0.53957	1.17765	0.56344	1.17508
0.56344	1.17508	0.58729	1.17240	0.61113	1.16960
0.61113	1.16960	0.63495	1.16668	0.65876	1.16364
0.65876	1.16364	0.68255	1.16046	0.70633	1.15715
0.70633	1.15715	0.73008	1.15370	0.75381	1.15009
0.75381	1.15009	0.77752	1.14632	0.80119	1.14238
0.80119	1.14238	0.82484	1.13826	0.84845	1.13395
0.84845	1.13395	0.87202	1.12942	0.89555	1.12466
0.89555	1.12466	0.91902	1.11964	0.94242	1.11431
0.94242	1.11431	0.96576	1.10868	0.98903	1.10271
0.98903	1.10271	1.01211	1.09622	1.03494	1.08910
1.03494	1.08910	1.05781	1.08157	1.08079	1.07361
1.08079	1.07361	1.10249	1.06368	1.12140	1.05016
1.12140	1.05016	1.13791	1.03364	1.15323	1.01561
0.11364	0.99999	0.11905	0.99986	0.12446	0.99974
0.12446	0.99974	0.12987	0.99962	0.13528	0.99950
0.13528	0.99950	0.14070	0.99938	0.14611	0.99924
0.14611	0.99924	0.15152	0.99908	0.15693	0.99888
0.15693	0.99888	0.16233	0.99863	0.16774	0.99834
0.16774	0.99834	0.17314	0.99803	0.17854	0.99768
0.17854	0.99768	0.18394	0.99732	0.18934	0.99694
0.18934	0.99694	0.19474	0.99654	0.20014	0.99612
0.20014	0.99612	0.20553	0.99570	0.21093	0.99525

0.21093	0.99525	0.21632	0.99480	0.22171	0.99432
0.22171	0.99432	0.22710	0.99384	0.23249	0.99334
0.23249	0.99334	0.23788	0.99282	0.24327	0.99230
0.24327	0.99230	0.24865	0.99175	0.25404	0.99120
0.25404	0.99120	0.25942	0.99063	0.26480	0.99005
0.26480	0.99005	0.27018	0.98945	0.27556	0.98885
0.27556	0.98885	0.28094	0.98823	0.28631	0.98760
0.28631	0.98760	0.29169	0.98696	0.29706	0.98630
0.29706	0.98630	0.30243	0.98564	0.30780	0.98496
0.30780	0.98496	0.31317	0.98428	0.31854	0.98358
0.31854	0.98358	0.32391	0.98287	0.32927	0.98216
0.32927	0.98216	0.33463	0.98143	0.34000	0.98070
0.34000	0.98070	0.34536	0.97996	0.35072	0.97921
0.35072	0.97921	0.35608	0.97845	0.36144	0.97768
0.36144	0.97768	0.36679	0.97691	0.37215	0.97612
0.37215	0.97612	0.37750	0.97533	0.38286	0.97454
0.38286	0.97454	0.38821	0.97374	0.39356	0.97293
0.39356	0.97293	0.39891	0.97212	0.40426	0.97130
0.40426	0.97130	0.40961	0.97048	0.41496	0.96965
0.41496	0.96965	0.42031	0.96881	0.42566	0.96798
0.42566	0.96798	0.43101	0.96714	0.43635	0.96629
0.43635	0.96629	0.44170	0.96545	0.44704	0.96460
0.44704	0.96460	0.45239	0.96375	0.45773	0.96289
0.45773	0.96289	0.46308	0.96204	0.46842	0.96118
0.46842	0.96118	0.47377	0.96033	0.47911	0.95947
0.47911	0.95947	0.48446	0.95861	0.48980	0.95775
0.48980	0.95775	0.49514	0.95689	0.50049	0.95603
0.50049	0.95603	0.50583	0.95518	0.51118	0.95432
0.51118	0.95432	0.51652	0.95347	0.52187	0.95262
0.52187	0.95262	0.52721	0.95177	0.53256	0.95092
0.53256	0.95092	0.53791	0.95008	0.54325	0.94924
0.54325	0.94924	0.54860	0.94840	0.55395	0.94757
0.55395	0.94757	0.55930	0.94674	0.56465	0.94592
0.56465	0.94592	0.57000	0.94510	0.57535	0.94429
0.57535	0.94429	0.58070	0.94348	0.58606	0.94268
0.58606	0.94268	0.59141	0.94188	0.59676	0.94109
0.59676	0.94109	0.60212	0.94031	0.60748	0.93954
0.60748	0.93954	0.61283	0.93877	0.61819	0.93801
0.61819	0.93801	0.62355	0.93726	0.62892	0.93652
0.62892	0.93652	0.63428	0.93578	0.63964	0.93506
0.63964	0.93506	0.64501	0.93434	0.65037	0.93364
0.65037	0.93364	0.65574	0.93294	0.66111	0.93226
0.66111	0.93226	0.66648	0.93158	0.67185	0.93092
0.67185	0.93092	0.67723	0.93026	0.68260	0.92962
0.68260	0.92962	0.68798	0.92899	0.69335	0.92837
0.69335	0.92837	0.69873	0.92777	0.70411	0.92717
0.70411	0.92717	0.70949	0.92659	0.71488	0.92602
0.71488	0.92602	0.72026	0.92547	0.72565	0.92493
0.72565	0.92493	0.73103	0.92440	0.73642	0.92388
0.73642	0.92388	0.74181	0.92338	0.74720	0.92290
0.74720	0.92290	0.75259	0.92242	0.75799	0.92197

0.75799	0.92197	0.76338	0.92153	0.76878	0.92110
0.76878	0.92110	0.77417	0.92069	0.77957	0.92029
0.77957	0.92029	0.78497	0.91991	0.79037	0.91954
0.79037	0.91954	0.79577	0.91919	0.80117	0.91886
0.80117	0.91886	0.80658	0.91855	0.81198	0.91825
0.81198	0.91825	0.81739	0.91796	0.82279	0.91769
0.82279	0.91769	0.82820	0.91744	0.83361	0.91721
0.83361	0.91721	0.83902	0.91699	0.84443	0.91679
0.84443	0.91679	0.84984	0.91661	0.85525	0.91645
0.85525	0.91645	0.86066	0.91630	0.86607	0.91617
0.86607	0.91617	0.87148	0.91606	0.87689	0.91596
0.87689	0.91596	0.88230	0.91588	0.88771	0.91581
0.88771	0.91581	0.89313	0.91577	0.89854	0.91574
0.89854	0.91574	0.90395	0.91575	0.90936	0.91578
0.90936	0.91578	0.91478	0.91585	0.92019	0.91597
0.92019	0.91597	0.92560	0.91613	0.93101	0.91635
0.93101	0.91635	0.93641	0.91661	0.94182	0.91692
0.94182	0.91692	0.94722	0.91728	0.95261	0.91769
0.95261	0.91769	0.95801	0.91815	0.96340	0.91866
0.96340	0.91866	0.96878	0.91921	0.97416	0.91982
0.97416	0.91982	0.97953	0.92048	0.98490	0.92119
0.98490	0.92119	0.99026	0.92196	0.99561	0.92278
0.99561	0.92278	1.00095	0.92365	1.00628	0.92459
1.00628	0.92459	1.01160	0.92558	1.01691	0.92663
1.01691	0.92663	1.02221	0.92774	1.02749	0.92892
1.02749	0.92892	1.03276	0.93016	1.03801	0.93146
1.03801	0.93146	1.04325	0.93284	1.04846	0.93428
1.04846	0.93428	1.05365	0.93581	1.05882	0.93741
1.05882	0.93741	1.06397	0.93909	1.06909	0.94085
1.06909	0.94085	1.07418	0.94270	1.07924	0.94464
1.07924	0.94464	1.08425	0.94668	1.08921	0.94883
1.08921	0.94883	1.09411	0.95110	1.09894	0.95348
1.09894	0.95348	1.10373	0.95598	1.10848	0.95860
1.10848	0.95860	1.11321	0.96134	1.11789	0.96422
1.11789	0.96422	1.12244	0.96726	1.12677	0.97052
1.12677	0.97052	1.13079	0.97404	1.13442	0.97784
1.13442	0.97784	1.13766	0.98193	1.14054	0.98627
1.14054	0.98627	1.14311	0.99083	1.14544	0.99557
1.14544	0.99557	1.14756	1.00045	1.14954	1.00544
1.14954	1.00544	1.15141	1.01051	1.15323	1.01561
0.11364	0.42522	0.12094	0.42442	0.12824	0.42355
0.12824	0.42355	0.13554	0.42263	0.14285	0.42167
0.14285	0.42167	0.15015	0.42070	0.15745	0.41974
0.15745	0.41974	0.16475	0.41880	0.17205	0.41787
0.17205	0.41787	0.17935	0.41691	0.18665	0.41591
0.18665	0.41591	0.19395	0.41485	0.20126	0.41371
0.20126	0.41371	0.20856	0.41251	0.21586	0.41123
0.21586	0.41123	0.22316	0.40990	0.23046	0.40850
0.23046	0.40850	0.23776	0.40705	0.24506	0.40554
0.24506	0.40554	0.25237	0.40397	0.25967	0.40235
0.25967	0.40235	0.26697	0.40067	0.27427	0.39893

0.27427	0.39893	0.28157	0.39712	0.28887	0.39526
0.28887	0.39526	0.29617	0.39333	0.30348	0.39133
0.30348	0.39133	0.31078	0.38927	0.31808	0.38714
0.31808	0.38714	0.32538	0.38494	0.33268	0.38267
0.33268	0.38267	0.33998	0.38033	0.34728	0.37793
0.34728	0.37793	0.35458	0.37546	0.36189	0.37292
0.36189	0.37292	0.36919	0.37030	0.37649	0.36761
0.37649	0.36761	0.38379	0.36483	0.39109	0.36195
0.39109	0.36195	0.39839	0.35897	0.40569	0.35588
0.40569	0.35588	0.41300	0.35267	0.42030	0.34934
0.42030	0.34934	0.42760	0.34588	0.43490	0.34232
0.43490	0.34232	0.44220	0.33867	0.44950	0.33493
0.44950	0.33493	0.45680	0.33111	0.46410	0.32723
0.46410	0.32723	0.47141	0.32330	0.47871	0.31932
0.47871	0.31932	0.48601	0.31531	0.49331	0.31128
0.49331	0.31128	0.50061	0.30723	0.50791	0.30314
0.50791	0.30314	0.51521	0.29897	0.52252	0.29466
0.52252	0.29466	0.52982	0.29017	0.53712	0.28545
0.53712	0.28545	0.54442	0.28046	0.55172	0.27516
0.55172	0.27516	0.55902	0.26949	0.56632	0.26341
0.56632	0.26341	0.57362	0.25688	0.58093	0.24985
0.58093	0.24985	0.58823	0.24227	0.59553	0.23409
0.59553	0.23409	0.60283	0.22529	0.61013	0.21587
0.61013	0.21587	0.61743	0.20597	0.62473	0.19570
0.62473	0.19570	0.63204	0.18520	0.63934	0.17458
0.63934	0.17458	0.64664	0.16397	0.65394	0.15352
0.65394	0.15352	0.66124	0.14330	0.66854	0.13346
0.66854	0.13346	0.67584	0.12397	0.68315	0.11415
0.68315	0.11415	0.69045	0.09293	0.69775	0.05445
0.69775	0.05445	0.70505	0.00000	0.71235	0.00000
0.71235	0.00000	0.71965	0.00000	0.72695	0.00000
0.72695	0.00000	0.73425	0.00000	0.74156	0.00000
0.74156	0.00000	0.74886	0.00000	0.75616	0.00000
0.75616	0.00000	0.76346	0.00000	0.77076	0.00000
0.77076	0.00000	0.77806	0.00000	0.78536	0.00000
0.78536	0.00000	0.79267	0.00000	0.79997	0.00000
0.79997	0.00000	0.80727	0.00000	0.81457	0.00000
0.81457	0.00000	0.82187	0.00000	0.82917	0.00000
0.82917	0.00000	0.83647	0.00000	0.84377	0.00000
0.84377	0.00000	0.85108	0.00000	0.85838	0.00000
0.85838	0.00000	0.86568	0.00000	0.87298	0.00000
0.87298	0.00000	0.88028	0.00000	0.88758	0.00000
0.88758	0.00000	0.89488	0.00000	0.90219	0.00000
0.90219	0.00000	0.90949	0.00000	0.91679	0.00000
0.91679	0.00000	0.92409	0.00000	0.93139	0.00000
0.93139	0.00000	0.93869	0.00000	0.94599	0.00000
0.94599	0.00000	0.95329	0.00000	0.96060	0.00000
0.96060	0.00000	0.96790	0.00000	0.97520	0.00000
0.97520	0.00000	0.98250	0.00000	0.98980	0.00000
0.98980	0.00000	0.99710	0.00000	1.00440	0.00000
1.00440	0.00000	1.01171	0.00000	1.01901	0.00000

```
1.01901   0.00000   1.02631   0.00000   1.03361   0.00000
1.03361   0.00000   1.04091   0.00000   1.04821   0.00000
1.04821   0.00000   1.05551   0.00000   1.06282   0.00000
1.06282   0.00000   1.07012   0.00000   1.07742   0.00000
1.07742   0.00000   1.08472   0.00000   1.09202   0.00000
1.09202   0.00000   1.09932   0.00000   1.10662   0.00000
1.10662   0.00000   1.11392   0.00000   1.12123   0.00000
1.12123   0.00000   1.12853   0.00000   1.13583   0.00000
1.13583   0.00000   1.14313   0.00000   1.15043   0.00000
1.15043   0.00000   1.15773   0.00000   1.16503   0.00000
1.16503   0.00000   1.17234   0.00000   1.17964   0.00000
1.17964   0.00000   1.18694   0.00000   1.19424   0.00000
1.19424   0.00000   1.20154   0.00000   1.20884   0.00000
1.20884   0.00000   1.21614   0.00000   1.22344   0.00000
1.22344   0.00000   1.23075   0.00000   1.23805   0.00000
1.23805   0.00000   1.24535   0.00000   1.25265   0.00000
1.25265   0.00000   1.25995   0.00000   1.26725   0.00000
1.26725   0.00000   1.27455   0.00000   1.28186   0.00000
1.28186   0.00000   1.28916   0.00000   1.29646   0.00000
1.29646   0.00000   1.30376   0.00000   1.31106   0.00000
1.31106   0.00000   1.31836   0.00000   1.32566   0.00000
1.32566   0.00000   1.33296   0.00000   1.34027   0.00000
1.34027   0.00000   1.34757   0.00000   1.35487   0.00000
1.35487   0.00000   1.36217   0.00000   1.36947   0.00000
1.36947   0.00000   1.37677   0.00000   1.38407   0.00000
1.38407   0.00000   1.39138   0.00000   1.39868   0.00000
1.39868   0.00000   1.40598   0.00000   1.41328   0.00000
1.41328   0.00000   1.42058   0.00000   1.42788   0.00000
1.42788   0.00000   1.43518   0.00000   1.44249   0.00000
1.44249   0.00000   1.44979   0.00000   1.45709   0.00000
1.45709   0.00000   1.46439   0.00000   1.47169   0.00000
1.47169   0.00000   1.47899   0.00000   1.48629   0.00000
1.48629   0.00000   1.49359   0.00000   1.50090   0.00000
1.50090   0.00000   1.50820   0.00000   1.51550   0.00000
1.51550   0.00000   1.52280   0.00000   1.53010   0.00000
1.53010   0.00000   1.53740   0.00000   1.54470   0.00000
1.54470   0.00000   1.55201   0.00000   1.55931   0.00000
1.55931   0.00000   1.56661   0.00000   1.57391   0.00000
2.50000
2.70000   2.90000   3.50000   4.30000   5.00000   6.00000
7.00000   8.30000  10.00240
10    0   0.10000
```

6.3 POTENTIAL FLOW CODE

6.3.1 Input Format

The steady mean flow problem on the finite element mesh is solved by the "inlflow" code. The following files are input:

Input File	Source
INLFLOW.INP	User Generated input file (see below)
INLMESH.DAT	Mesh "restart" file created by "inlmesh" (See Section 6.2.2)

INLFLOW.INP has only one card and the input data is formatted. The card is a maximum of 80 characters. Except for special cases, this file will probably not need to be changed from one run to the next. The input variables should be placed in INLFLOW.INP in the sequence described below:

Card	Variable	Format	Description
1	NTYPE	I5	= 1, calculates the mean flow velocity potential for flow from infinity into a blank inlet duct = 2, calculates the velocity potential for the inlet duct flow alone = 3, calculates both cases sequentially and writes the solution vector to disk for use by the inlet radiation code. This is the usual choice.
	PRINT1	I5	(Not Used) ≠ 0, beginning row and column of the assembled stiffness matrix to be printed = 0, do not print
	PRINT2	I5	(Not Used) ≠ 0, final row and column of the assembled stiffness matrix to be printed = 0, do not print
	NPLOT	I5	(Not Used) = 0, contour plotting routine bypassed matrix to be printed = 1, plot contour level curves for the solution vector
	NPRINT	I5	= 0, do not print nodal coordinate array = 1, print nodal coordinate array

6.3.2 Output Files

The Potential Flow Code, "inlflow", outputs the following files:

Output File	Output File Name	When Created	What is in it?
General Output	INLFLOW.OUT	Always	Information about the case being run. Solution for the two mean flow calculations.
Potential flow field "restart" file	INLFLOW.DAT	Always	The nodal mean flow velocity potential required by "inlrad" or "inlrad3d"
Postscript plotting file	INLFLOW.PS	Always	Contour Plots of potential flow field for the two separate potential flow calculations.
Temporary work files	fort.2 fort.3 fort.4 fort.8 Temporary files 1, 15, 16, 17, 18	Always	These files are output to user's computer.

6.3.3 Sample Input

This sample potential flow module input file comes from the inlet radiation code's "TFaNS1.5/inlrad.v4.0/testcases" subdirectory.

```
    3    0   10    1    0
```

6.4 EVERSMAN RADIATION MODULE

6.4.1 Input Format

Input data files for the Eversman inlet radiation code, "inlrad", are shown below:

Input File	Source
INLRAD.INP	User Generated input file (see below)
INLMESH.DAT	Mesh "restart" file created by "inlmesh" (See Section 6.2.2)
INLFLOW.DAT	Potential flow "restart" file created by "inlflow" (See Section 6.3.2)

The input data has been structured into cards. Each card of data begins on a new line and the input data is formatted. The acoustic radiation program is capable of running multiple cases. It contains the data for all the cases with an alphanumeric input separating the data for any two cases which determines whether the case is to be run or not.

The code has two options which will output files for post processing:

- NPOST = 1 will output a postscript file containing eight radiation plots.
- NPOST = 2 produces the data file for contour plotting using alternative contour plotting software.

The input format for the user generated input file, "INLRAD.INP", is given below:

Card	Variable	Format	Description
1	HDR(I)	14A4	I = 1,14 (Character*4); This card is used for two purposes: • It is the title card for each case or • It is the last card in the file where HDR(1) = 'STOP'. When STOP is placed in the first four columns, the program stops execution. Thus this card also controls the running of multiple cases by determining where the program will stop.
2	NSYM	I10	= 0, Two Dimensional duct = 1, circular or annular duct
	ETAR	F10.5	Nondimensional frequency of the sound source ($\eta_r = \omega R/c_r$) ω = fan rotational frequency in rad/sec R = outer duct radius at the input plane c_r = freestream speed of sound outside the nacelle
	NIMP	I10	= 1, acoustic liner is given by specifying admittances = 2, acoustic liner is given by specifying impedances
	MTHETA	I5	Circumferential mode order (angular mode number), m

2	NPOS	I5	No. of radial mode orders for circumferential mode order, m. Set NPOS = 0 here if NPOS > 0 during the mesh calculation in "inlmesh". This means radial mode calculations were done in "inlmesh". Set NPOS > 0 here if NPOS = 0 during the mesh calculation in "inlmesh". This means that MTHETA and NPOS are required in "inlrad" to do the radial mode calculations since they were not done in "inlmesh".
3	PRINT1	I5	(Not Used) $\neq$ 0, Beginning row and column in stiffness matrices printed = 0, Beginning row and column in stiffness matrices not printed
	PRINT2	I5	(Not Used) $\neq$ 0, Final row and column in stiffness matrices printed = 0, Final row and column in stiffness matrices not printed
	NPLOT	I5	(Not Used) > 0, level curves for the solution vector plotted = 0, plotting routine bypassed
	NCONT	I5	Number of contours to be plotted (Postscript plots only)
	CMAXO	F10.5	Value of maximum contour level (Overriden by code)
	CMINO	F10.5	Value of minimum contour level (Overriden by code)
4	ZAI(I)	6F10.5	I = 1, NPOS; complex incident modal amplitudes non−dimensionalized by (RHOFS)(CFS)^2, (complex: real and imaginary parts, three per card). 2 x NPOS numbers need to be input.
5	NLINO	I5	Number of acoustically lined elements on the duct outer surface, see Figure 15 (if NLINO =0 there is no lining and ZADMO need not be input)
	MBEGO	I5	Element number (counted along the duct outer surface from the input plane) on which the lining begins, see Figure 15.
	NLINI	I5	Number of acoustically lined elements on the duct inner surface, see Figure 15 (if NLINI =0 there is no lining and ZADMI need not be input)
	MBEGI	I5	Element number (counted along the duct inner surface from the input plane) on which the lining begins, see Figure 15.
6	ZADMO(I, J)	6F10.5	Input only if NLINO > 0; This parameter is specified at the frequency being run and is non−dimensionalized by the local density x acoustic speed. I = 1, NLINO, J = 1,3; If NIMP = 1, input admittances in each treated node of an element on the duct outer surface (complex: real and imaginary parts, one element per card) If NIMP = 2, input impedances in each treated node of an element on the duct outer surface (complex: real and imaginary parts, one element per card)

7	ZADMI(I,J)	6F10.5	Input only if NLINI > 0; This parameter is specified at the frequency being run and is non−dimensionalized by the local density x acoustic speed. I = 1, NLINI, J = 1,3; If NIMP = 1, input admittances in each treated node of an element on the duct inner surface (complex: real and imaginary parts, one element per card) If NIMP = 2, input impedances in each treated node of an element on the duct inner surface (complex: real and imaginary parts, one element per card)
8	NPOST	I5	= 1, Acoustic pressures for contour plotting are calculated at the nodes and the postscript plotting routines are used for pressure contour plotting. = 2, Acoustic pressures for contour plotting are calculated at the Gauss points in the elements and a data file for a suitable alternative contour plotter (e.g. TECPLOT) is produced.
9	VMIN	F10.0	Average compressible inlet Mach number at input plane (positive for inlet flow and based on local sound speed)
	CFS	F10.0	Free stream (far from the nacelle) speed of sound (ft/sec)
	RHOFS	F10.0	Free stream (far from the nacelle) density ($lb_f - s^2/ft^4$)
10	XSHIFT	F10.5	Axial shift of the origin non−dimensionalized by the input plane outer duct radius. Positive value of XSHIFT means shift to the left, i.e. shift towards the inlet (Use the opposite sign as in the mesh generation routine to get back to the original origin) This parameter determines where the origin of the measurement arc will be placed. *Note:* It is important to assure that the shift, XSHIFT, and arc (arc radius = RM) are not so large that some of it is outside the grid. If the radius is too large, it will be detected and the maximum permissible radius will be used. Similarly, be sure that the measurement radius is not so small that the arc is in the conventional element region. Post processing assumes the directivity is to be obtained in the wave envelope region.
	RM	F10.5	Measurement arc radius non−dimensionalized by the input plane duct radius (see note above).
11	NBAFL	I10	= 0, The baffle admittance option is not used = 1, The baffle admittance option is used
	ZAB	2F10.5	Admittance on the baffle used to produce absorption non−dimensionalized by RHOFS*CFS, real and imaginary parts

12	XLEFT	F10.5	X coordinate (non−dimensionalized by the input plane radius) of left end (aft−most point) of sideline measurement line. (has to be in the computational domain)
	XRIGHT	F10.5	X coordinate (non−dimensional) of right end of sideline measurement line.
	RSIDE	F10.5	Distance of the measurement line from the duct axis. (be sure this is far enough away not to pass into the standard element domain)
13	HDR(I)	14A4	If another case is being run, this card is setup like Card 1. Otherwise place the word STOP as the first four characters on this line to end execution.

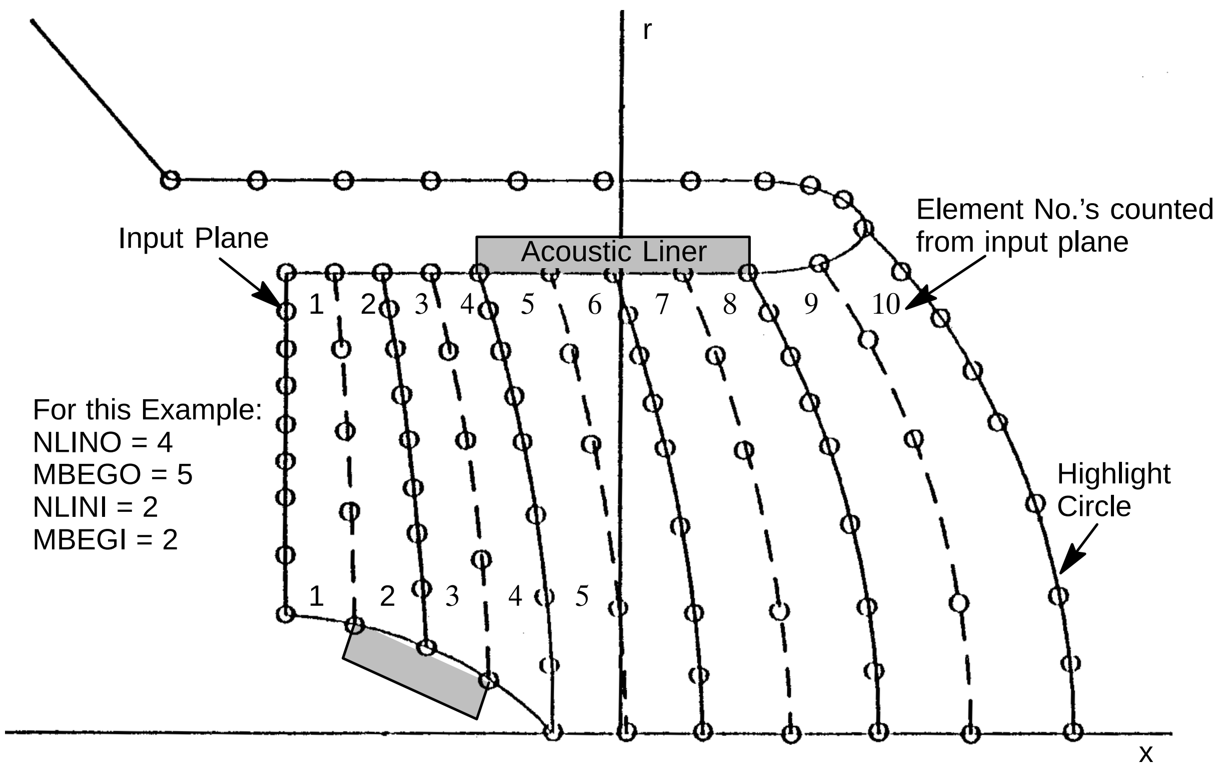


Figure 15: Creating Acoustic Liners on the Inner and Outer Surfaces of a Nacelle Inlet (or nozzle)

6.4.2 Sample Input

This sample Eversman Radiation module input file comes from the inlet radiation code's "TFaNS1.5/inlrad.v4.0/testcases/tst.src" subdirectory. This test case contains contains no acoustic treatment and contains only one case. To run multiple cases, the word stop at the bottom would be replaced by the title for the next case. All other parameters would then be input. When the desired number of cases were input, then a STOP would be placed as the last line in the file on the first four columns of the line.

```
Single case Run (9,2) mode
        1  25.20856         2    9    6
    1    9    1    5     -20.0      20.0
     0.000     0.000     0.000     0.000      1.00      0.00
     0.000     0.000     0.000     0.000      0.00      0.00
    0    0    0    0
   1
    0.3095 1116.4623  .0023766
     -0.50  10.00240
         0       0.8       0.0
      -1.0       6.0       4.0
STOP
```

6.4.3 Output Files

The Eversman Inlet Radiation Code, “inlrad”, outputs the following files:

Output File	Output File Name	When Created	What is in it?
General Output	INLRAD.OUT	Always	Mode eigenvalues and eigenfunctions (mode shapes), if NPOS > 0. User input Certain mesh parameters Reflected and transmitted modal amplitudes Partial solution vector
Far Field Directivity File	inldirect.input	Always	Non−dimensional directivities for the circumferential mode order, m, given the mode amplitudes, ZAI, input.
Postscript plotting file	INLRAD.PS	when NPOST = 1. when NPOST = 2	Postscript Contour Plots and directivity Plots for each mode normalized to 100dB
Acoustic Pressure Output formatted for use by other contour plotting codes	INCONT.DAT INCONT2.DAT	when NPOST = 2	Acoustic pressure plotting file for contour plotting on alternative plotting software (e.g. TECPLOT)
Temporary work files	fort.3 ATTEN1.DAT ATTEN2.DAT ATTEN3.DAT ATTEN4.DAT ATTEN5.DAT	Always	These files are output to user’s machine.

There are two options on the manner in which the acoustic pressure contour plot data is calculated:

- NPOST = 1: Only the following postcript oriented postprocessing is done.

  In this version the acoustic pressure is evaluated at each finite element node. This requires the calculation of the mean flow velocity at these nodes and the calculation of the derivative of the acoustic potential at these nodes. The derivatives required for the mean flow velocity and the acoustic pressure are not unique at a given node when calculated from the different elements that share that node. An averaging technique based on the calculation of the derivatives at the node in all elements common to the node was used. A plotting routine compatible with the nodal description of the pressure field is part of the code. Even with apparently smooth solutions for acoustic potential, the non−uniqueness of the derivatives at nodes may cause pressure contours which are not smooth. This is reduced if the mesh is made more dense, but this increase in mesh density is not generally seen to substantially improve

the acoustic potential solution. The pressure in the outer region of infinite elements seems to be much less degraded when pressure is computed from potential.

Plots available are:

1. Zoomed acoustic potential contours for standard elements.
2. Acoustic potential full grid including infinite elements.
3. Acoustic pressure full grid including infinite elements.
4. Cartesian plot of SPL versus angle from the axis at specified radius from specified center.
5. Cartesian plot of acoustic pressure versus angle from the axis at specified radius from specified center.
6. Polar directivity at specified radius relative to specified center.
7. Sideline SPL directivity on a line parallel to the duct axis and with specified end points.
8. Sideline acoustic pressure directivity on a line parallel to the duct axis and with specified end points.

- NPOST = 2: Outputs same file as NPOST = 1, plus two files for plotting contour curves on an alternative plotting routine.

  This version retains all of the postcript postprocessing above.

  This version produces data for plotting of contour curves on software such as TECPLOT.

  The acoustic pressure is in this version the acoustic pressure is evaluated on a 2 x 2 grid of Gauss points in each rectangular element and on a grid of 4 Gauss points in each triangular element. In infinite elements evaluation is on a grid of 25 x 2 points in each element (the code can be easily modified to change this, but this seems to be sufficient). The radial extent of the resulting SPL contour plots can also be easily modified in the code. This produces unique values of the acoustic pressure at every plotting point. The plotting points are arranged in an unstructured grid and therefore in TECPLOT the triangulation option must be used. This requires an additional boundary zone describing the baffle, nacelle, and centerbody in a separate file. TECPLOT files are named “INCONT.DAT” (contour plotting points) and “INCONT2.DAT” (boundary plotting points).

6.5 RADIATION MODULE MODIFIED FOR TFaNS

This version of the radiation module was modified by Pratt & Whitney to run with TFaNS. Changes to the original code include:

- Capability to run multiple modes and harmonics with unit (m, μ) mode input.
- Dimensional input format based on standard geometry and performance parameters
- An Acoustic Properties File is output for use by CUP3D.

The system is designed so that it, in effect, reruns each (m, μ) mode one at a time. Note that multiple harmonics of BPF are run with the same mesh. Thus, a user generated mesh must be capable of being accurate for the highest BPF harmonic required.

Notes:

- For this case, modes should not be calculated in the mesh generator since they will be ignored by this version of the acoustic radiation calculation.
- The multiple case capability for this version of the radiation module will not run correctly and thus should not be used.

6.5.1 Input Format

Input data files for the TFaNS version of the inlet radiation code, "inlrad3d", are shown below:

Input File	Source
INLRAD.INP	User Generated input file (see below)
INLMESH.DAT	Mesh "restart" file created by "inlmesh" (See Section 6.2.2)
INLFLOW.DAT	Potential flow "restart" file created by "inlflow" (See Section 6.3.2)

The input data for the user generated input file, "INLRAD.INP", has been structured into cards. Each card of data begins on a new line. The input file contains a mixture of free format and fixed format information. The file format is given below:

Line	Variable	Format	Description
1	HDR(I)	14A4	Alphanumeric Title (only the first 56 characters will be read)
2	DUM	A80	Dummy Card used to identify items in card below
3	NSYM	Free format	= 0, Two Dimensional duct = 1, circular or annular duct
	NIMP	Free format	= 0, acoustic liner is given by specifying admittances = 1, acoustic liner is given by specifying impedances
4	DUM	A80	Dummy Card used to identify items in card below
5	NHT	Free format	Number of harmonics being predicted (be sure mesh is fine enough to resolve the required frequencies)

5	NBLADE	Free format	Number of rotor blades
	NVANE	Free format	Number of stator vanes (creates m = n*NBLADE−k*NVANE per Ref. 15)
6	DUM	A80	Dummy Card used to identify items in card below
7	DINPT	Free format	Duct Diameter at the input plane (inches)
	DFAN	Free format	Duct diameter at Fan Leading Edge Tip Location (inches) (All length dimensions are non−dimensionalized by this in the output files: “inlrad”, “inldirect.input”)
	N1C	Free format	Corrected fan speed (rpm)
8	DUM	A80	Dummy Card used to identify items in card below
9	VMIN	Free format	Mass Averaged compressible Mach number, fan l.e. (positive for inlet flow and based on local sound speed)
	TAMB	Free Format	Far field static temperature (^{o}R)
	PAMB	Free format	Far field static pressure (psf)
10	DUM	A80	Dummy Card used to identify items in card below
11	XSHIFT	Free format	Axial shift of the origin non−dimensionalized by the input plane outer duct radius. Positive value of XSHIFT means shift to the left, i.e. shift towards the inlet (Use the opposite sign as in the mesh generation routine to get back to the original origin) This parameter determines where the origin of the measurement arc will be placed. *Note:* It is important to assure that the shift, XSHIFT, and arc (arc radius = RM) are not so large that some of it is outside the grid. If the radius is too large, it will be detected and the maximum permissible radius will be used. Similarly, be sure that the measurement radius is not so small that the arc is in the conventional element region. Post processing assumes the directivity is to be obtained in the wave envelope region.
	RM	Free format	Measurement arc radius non−dimensionalized by the input plane duct radius (see note above).
	CUTOFF	Free format	Smallest cutoff ratio for an (m, μ) mode where the code will perform a radiation calculation (not presently used)
12	PRINT1	I5	(Not Used) ≠ 0, Beginning row and column in stiffness matrix printed = 0, Beginning row and column in stiffness matrix not printed
	PRINT2	I5	(Not Used) ≠ 0, Final row and column in stiffness matrix printed = 0, Final row and column in stiffness matrix not printed
	NPLOT	I5	(Not Used) > 0, level curves for the solution vector plotted = 0, plotting routine bypassed
	NCONT	I5	Number of contours to be plotted (Postscript plots only)

12	CMAXO	F10.5	Value of maximum contour level (Overriden by code)
	CMINO	F10.5	Value of minimum contour level (Overriden by code)
13	NLINO	I5	Number of lined elements on the duct outer surface, see Figure 15. (if NLINO =0 there is no lining and ZADMO need not be input)
	MBEGO	I5	Element number (counted along inlet outer surface from the input plane) on which the lining begins, see Figure 15.
	NLINI	I5	Number of lined elements on the duct inner surface, see Figure 15. (if NLINI =0 there is no lining and ZADMI need not be input)
	MBEGI	I5	element number (counted along inlet inner surface from the input plane) on which the lining begins, see Figure 15.
14	ZADMO(I,J)	6F10.5	Input only if NLINO > 0; This parameter is specified at the frequency being run and is non−dimensionalized by the local density x acoustic speed. I = 1, NLINO, J = 1,3; If NIMP = 1, input admittances in each treated node of an element on the duct outer surface (complex: real and imaginary parts, one element per card) If NIMP = 2, input impedances in each treated node of an element on the duct outer surface (complex: real and imaginary parts, one element per card)
15	ZADMI(I,J)	6F10.5	Input only if NLINI > 0; This parameter is specified at the frequency being run and is non−dimensionalized by the local density x acoustic speed. I = 1, NLINI, J = 1,3; If NIMP = 1, input admittances in each treated node of an element on the duct inner surface (complex: real and imaginary parts, one element per card) If NIMP = 2, input impedances in each treated node of an element on the duct inner surface (complex: real and imaginary parts, one element per card)
16	NPOST	I5	= 1, Acoustic pressures for contour plotting are calculated at the nodes and the postscript plotting routines are used for pressure contour plotting. = 2, Acoustic pressures for contour plotting are calculated at the Gauss points in the elements and a data file for a suitable alternative contour plotter (e.g. TECPLOT) is produced.
17	NBAFL	I10	= 0, The baffle admittance option is not used = 1, The baffle admittance option is used
	ZAB	2F10.5	Admittance on the baffle used to produce absorption non−dimensionalized by RHOFS*CFS, real and imaginary parts

18	SLON	F10.5	< 1.0 No Sideline Plotting ≥ 1.0 Plot Sideline
	XLEFT	F10.5	X coordinate (non−dimensionalized by the input plane radius) of left end (aft−most point) of sideline measurement line. (has to be in the computational domain)
	XRIGHT	F10.5	X coordinate (non−dimensional) of right end of sideline measurement line.
	RSIDE	F10.5	Distance of the measurement line from the duct axis. (be sure this is far enough away not to pass into the standard element domain)
19	HDR(I)	14A4	Place the word “STOP” as the first four characters on the line

6.5.2 Sample Input

This sample TFaNS Radiation module input file comes from the inlet radiation code’s “TFaNS1.5/inlrad.v4.0/testcases/tst.aftrad3d” subdirectory. This test case contains contains no acoustic treatment and contains only one case. Multiple cases should not be run with this code.

```
Sample input file
 NSYM                   NIMP
 1                       1
NHT            NBLADE                 NVANE
3                18                    45
DINPT          DARRAY                 N1C
21.9996        22.000                 5424.
MX             TAMB                   PAMB
0.3095          518.7                  2116.
XSHIFT         RM                     CUTOFF
-0.50           10.00240               0.9
    1    9    1    5     -20.0       20.0
   0
   1
        0      0.80
      0.00      -1.0        6.0       4.0
STOP
```

6.5.3 Output File Structure

The TFaNS version of the Inlet Radiation Code, “inlrad3d”, outputs the following files:

Output File	Output File Name	When Created	What is in it?
General Output	INLRAD.OUT	Always	Modes being calculated and mode eigenvalues and eigenfunctions (mode shapes) User input Certain mesh parameters Reflected and transmitted modal amplitudes Partial solution vector
Inlet Radiation Acoustic Properties File (for CUP3D)	inlrad	Always	Header cards Scattering coefficients Far−field directivities
Far Field Directivity File (unit input)	inldirect.input	Always	Non−dimensional directivities for each (m, μ) mode given unit input
Postscript plotting file	INLRAD.PS	Always	Contour Plots and directivity Plots for each mode normalized to 100dB
Acoustic Pressure Output formatted for use by other contour plotting codes.	INCONT.DAT INCONT2.DAT	when NPOST = 2	Acoustic pressure plotting file for contour plotting (with modifications) on alternative plotting software (e.g. PLOT3D, TECPLOT). May not work for the multiple modes run here.
Temporary work files	fort.3 ATTEN1.DAT ATTEN2.DAT ATTEN3.DAT ATTEN4.DAT ATTEN5.DAT	Always	These files are output to user’s machine.

6.6 RUNNING THE SYSTEM

6.6.1 Mesh Generation

Input File	Source
INLPRE.INP	User Generated input file (see Section 7.2.1) Assumes the inlet and centerbody surfaces need to be spline fitted. This file is used by Option 1 (see below)
INLMESH.INP	User Generated input file (see Section 7.2.1) Assumes the user can input the finite element inlet and centerbody three node line elements (surface node locations) for Region I. This file is also generated if option 1 of “inlmesh” is run. This file is used by Option 2 (see below)

To run the code:

1. Create one of the input files shown above.

2. Bring up a command tool in the subdirectory where this file resides.

3. Make sure the “inlmesh” executable is accessible from the “TFaNS1.5/bin” subdirectory.

4. Type the following command:

   inlmesh

5. The code will then ask:

   WHAT OPTION DO YOU WANT TO RUN, 1 OR 2 ?

   If you are using the file INLPRE.INP, type 1.
   If you are using the file INLMESH.INP, type 2.

6.6.2 Potential Flow

Input File	Source
INLFLOW.INP	User Generated input file (see Section 6.3.1)
INLMESH.DAT	Mesh “restart” file created by “inlmesh” (See Section 6.2.2)

To run the code:

1. Create the input files shown above.

2. Bring up a command tool in the subdirectory where these files reside.

3. Make sure the “inlflow” executable is accessible from the “TFaNS1.5/bin” subdirectory.

4. Type the following command:

    inlflow &

   The “&” permits the code to be run in background. If it is left off the code will be run in the foreground.

6.6.3 Eversman Radiation

Input File	Source
INLRAD.INP	User Generated input file (see Section 6.4.1)
INLMESH.DAT	Mesh “restart” file created by “inlmesh” (See Section 6.2.2)
INLFLOW.DAT	Potential flow “restart” file created by “inlflow” (See Section 6.3.2)

To run the code:

1. Create the input files shown above.

2. Bring up a command tool in the subdirectory where these files reside.

3. Make sure the “inlrad” executable is accessible from the “TFaNS1.5/bin” subdirectory.

4. Type the following command:

    inlrad

5. Answer the following questions:

   ORDER OF THE INFINITE ELEMENTS MULTIPOLE?
   10
   ORDER OF INTEGRATION IN INFINITE ELEMENTS ?
   12

Notes on step 5, Console Input:

You will be asked to specify the order of the multipole represented by the infinite element interpolation. the number of nodes in an infinite element is three times the multipole order. Choices for multipole order are presently 8, 9, 10.

W. Eversman has performed tests with 8th, 9th, and 10th order multipoles (24, 27, and 30 pressure nodes) with evidence of improving performance with increased multipole order.

You will also be asked to specify the integration points in the infinite elements in the radial direction (“$\xi-$direction”). The number of integration points in the spherical direction (“$\eta-$direction”) is always 3.

For any choice of pressure nodes the choices for integration points is 9, 10, 12, 16:

The choice of 16 is probably more than is needed and is thus, not checked out.

The following options seem to work reasonably well:

Multipole order 8−−24 pressure nodes−−9 integration points.
Multipole order 9−−27 pressure nodes−−10 integration points.
Multipole order 10−−30 pressure nodes−−12 integration points.

Testing may show that these can be reduced.

W. Eversman's recommended general purpose choice presently is multipole order 10 and 12 integration points.

In general, use of infinite elements allows a smaller standard element mesh, and improved accuracy by reducing reflections from the boundary between the standard elements and the outer region.

6.6.4 TFaNS Radiation

Input File	Source
INLRAD.INP	User Generated input file (see Section 6.5.1)
INLMESH.DAT	Mesh "restart" file created by "inlmesh" (See Section 6.2.2)
INLFLOW.DAT	Potential flow "restart" file created by "inlflow" (See Section 6.3.2)

To run the code:

1. Create the input files shown above.

2. Bring up a command tool in the subdirectory where these files reside.

3. Make sure the "inlrad3d" executable is accessible from the "TFaNS1.5/bin" subdirectory.

4. Type the following command:

   inlrad3d

5. Answer the following questions (see previous section for notes on this console input):

   ORDER OF THE INFINITE ELEMENTS MULTIPOLE?
   10
   ORDER OF INTEGRATION IN INFINITE ELEMENTS ?
   12

7. EVERSMAN AFT RADIATION CODE

7.1 GENERAL ORGANIZATION OF THE AFT RADIATION CODE

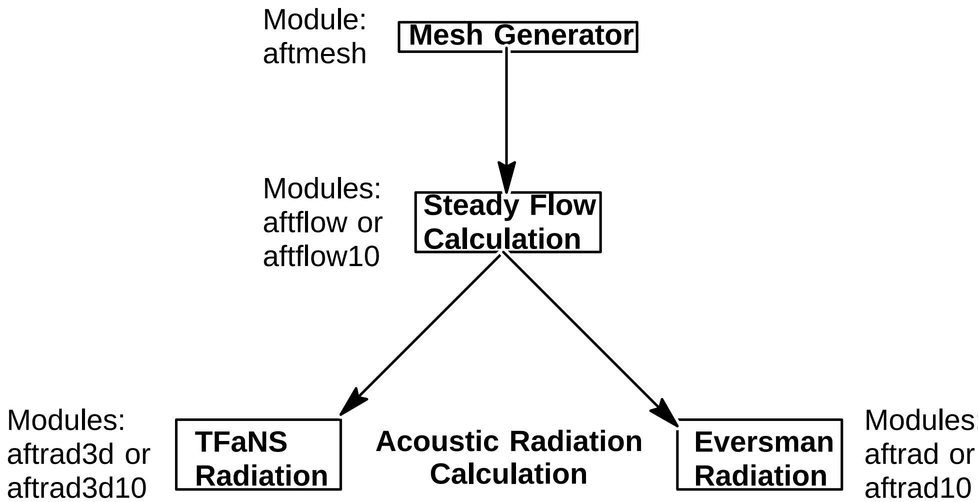


Figure 16: General Organization of the Aft Radiation Code

Figure 16 shows the general organization of the aft radiation code. The code is composed of a number of modules which are run in sequence by the user. These modules can be grouped into three main parts (see Figure 16):

1. Mesh Generator (see Section 7.2)

2. Steady Flow Calculation (see Sections 7.3)

3. Acoustic Radiation Calculation (see Sections 7.4 and 7.5)

Acoustic radiation can be calculated in one of two ways:

a. *Eversman Radiation:* In this case the code is not being run as a part of TFaNS. The code is run one circumferential mode order (for multiple radial mode orders) at a time.

b. *TFaNS Radiation:* In this case the code is being run as part of TFaNS. This case will output the Acoustic Properties File needed for CUP3D.

The parts of the code will now be discussed in further detail with reference to Figure 16:

Mesh Generator

The “aftmesh” module (see Figure 16) generates the computational finite element mesh for the nacelle nozzle of interest. It may also calculate acoustic mode information which is used by the Eversman radiation module. This information is output to a file to be used by all other modules. See Section 7.2 for more information.

Steady Flow Calculation

This part of the code calculates two steady potential flow solutions for the computational domain. A file is output for use by the radiation modules. There are two versions of this code:

- "aftflow" places temporary work files on the user's workstation while the code is running.
- "aftflow10" places temporary work files in the "/tmp" subdirectory while the code is running. This module has worked correctly on Sun SPARC workstations at Pratt & Whitney.

Acoustic Radiation Calculation

The radiation calculation performs the following calculations:

- It combines the two potential flow solutions with mean axial Mach numbers at the input plane and in the far−field. This forms the steady flow for the radiation calculation.
- It may calculate the mode eigenfunctions required for the radiation calculation (if not computed in "aftmesh")
- It calculates the far−field directivities for a given frequency and mode input.

This calculation can take on two forms:

A. Eversman Radiation

If the radiation code is being run independently of TFaNS, then this option may be used to calculate far−field directivities given mode amplitudes for a circumferential mode order, m. Far−field directivities non−dimensionalized by $\rho_\infty c_\infty^2$ are output where ρ_∞ is the static density in the far−field and c_∞ is the static acoustic speed in the far field.

There are two versions of this code:

- "aftrad" places temporary work files on the user's workstation while the code is running. These files require up to (and maybe more than) 250 megabytes of hard drive while the code is running.
- "aftrad10" places temporary work files in the "/tmp" subdirectory while the code is running. This module has worked correctly on Sun SPARC workstations at Pratt & Whitney.

See Section 7.4 for more information.

B. TFaNS Radiation

If the radiation code is being run as a part of TFaNS, then this option should be used to create an acoustic properties file.

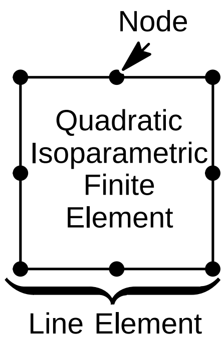
There are two versions of this code:

- "aftrad3d" places temporary work files on the user's workstation while the code is running. These files require up to (and maybe more than) 300 megabytes of hard drive while the code is running.
- "aftrad3d10" places temporary work files in the "/tmp" subdirectory while the code is running. This module has worked correctly on Sun SPARC workstations at Pratt & Whitney.

See Section 7.5 for more information

Terms Utilized by This Section

There are terms utilized by this section which are explained briefly below:



Computational Mesh: Grid of finite elements needed to find the solution.

Finite Element: A finite sub–domain in which the solution is approximated. The number of elements per wavelength will affect the solution (see Section 7.2.3).

Node: Points where the equations of motion are discretized. The code also uses “shape functions” which determine how to interpolate the solution within each element for specified values of the solution at the nodes. There are eight nodes per element for quadrilateral elements, and six nodes per element for triangular elements.

Line Element: Entire length of one side of an element. This term is used to describe the surfaces on the nacelle and centerbody.

The technical documentation for the aft radiation code may be found in References 6 to 8.

7.2 MESH GENERATOR

7.2.1 Input Format

The finite element mesh generation code "aftmesh" generates the finite element mesh for the computation of the far field radiation from an engine fan nozzle. The program is dimensioned using parameter statements. The input data file structure has distinct blocks of input data referred to as cards. Each card begins on a new line and the input data on the card is generally formatted. The data format determines the maximum line length. If there is more data than can fit on one line, a card is continued on additional lines. The input variables should be input in the file in the sequence given.

There are four regions of the computational domain described in the input data (See Figure 17). Region I is within the duct bounded by the duct exit plane. The number of elements axially in this region is determined by the number of line elements on the inner duct surface. Region II extends from the exit plane to the end of the shear layer. Region III extends from the end of the shear layer to the wave envelope elements. The wave envelope elements are in Region IV. The length of the exhaust jet region (Region II) is controlled by the line elements defined on the centerline. The last node terminates the jet region via a circular arc which intersects the shear layer. This circle is referred to as the "highlight circle" in this code.

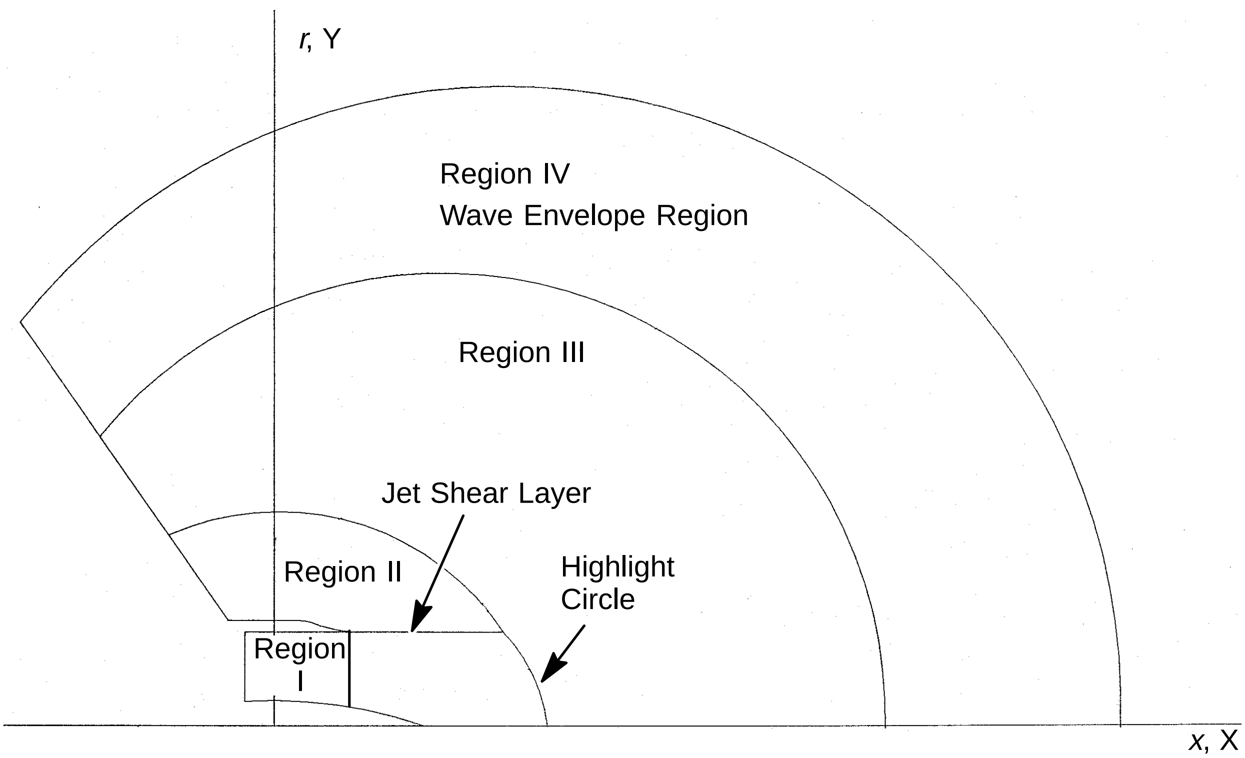


Figure 17: Aft computational domain showing the boundaries and regions

The mesh generator calculates the mesh in two parts. The first part of the program uses a spline curve fit procedure for the nozzle fan duct and centerbody geometry. For this part the user must supply enough x and r coordinates (also called X and Y coordinates in the code) to define the shape of the outer nacelle, the inner duct, and the centerbody. Using the spline information, the surfaces of the nacelle are discretized into line elements whose end points are defined. The center node of the

elements is created from the knowledge of the end points. The curve fit is a natural cubic spline. The second part generates the mesh using a mesh generation scheme for the spline fitted nacelle.

There are two options for running the mesh generator:

Option	**Option 1**	**Option 2**
What it runs	Runs both parts of the code: 1) Spline fits the nacelle boundaries and centerbody 2) Generates the mesh	Runs the second part of the code only to generate the mesh based on boundary element definitions given by the user.
Input file	AFTPRE.INP	AFTMESH.INP
Best time to use	Used when: 1) Starting from scratch with a nacelle 2) When altering the mesh resolution on the nacelle boundaries.	AFTMESH.INP would have typically been generated in a prior run using Option 1. Could be used when: 1) Changing things not associated with the nacelle geometry. 2) Modifying boundary elements from those generated by the spline fit.

Mode (eigenvalue/eigenvector) information for either option can either be calculated in the mesh generator or radiation module:

To calculate mode eigenvalues/eigenfunctions in:	Mesh generator ("aftmesh")	Radiation module
In the mesh generator set NPOS equal to:	No. of radial mode orders being run	0 (zero)
Best time to use	Useful if user has a special application	1) User is running the TFaNS version of the radiation code, "aftrad3d" or "aftrad3d10". 2) User would like to run mode calculations in standard Eversman radiation module

Figure 18 and Figure 19 can be consulted for details of the computational region which are relevant to the mesh generation.

7.2.1.1 Input Running Option 1: Spline Fit Nacelle Boundaries, Calculate Mesh.

The input plane, shown in Figure 18, refers to the radial plane in the duct (at an axial location) where the noise is input in terms of modal amplitudes.

The first card is a header card allowing a maximum of 72 characters. It is formatted (18A4). It is not counted in the card sequence numbers defined below.

The input is a combination of formatted and free format data. Each card of data begins on a new line.

All lengths are non−dimensionalized by the outer duct radius at the input plane.

Card	Variable	Format	Description
1	NELU	Free Format	Number of line elements describing the upper surface of the nacelle. (NLINU in Option 2). Establishes near field finite element (FEM) mesh density (Figure 18). *Note:* Number of points (nodes) on the upper nacelle surface is NELU + 1.
	NELI	Free Format	Number of line elements describing the inner surface; also number of elements on the centerbody within the duct between the input plane and the exit plane (NLINLI in Option 2). Establishes near field FEM mesh density (Figure 18). *Note:* Number of points (nodes) on the inner nacelle surface is NELI + 1.
	NELC	Free Format	Number of line elements on the centerbody and centerline beyond the transition region (between the transition region and the end of Region II). Establishes near field FEM mesh density (Figure 18). *Note:* Number of points (nodes) on the centerbody beyond the transition region is NELC + 1.
	NELT	Free Format	Number of elements in the transition region which couples the inner duct to the jet. In this region, the axial mesh resolution is the same as the last element inside the duct. The transition region is part of Region II. Establishes near field FEM density. NELT = 5 is a reasonable choice (Figure 18). *Note:* The total number of elements in the jet (Region II) is NLINLC = NELT+NELC. The outer centerbody is that portion of the centerbody and centerline beyond the transition zone (Figure 18).
2	XBAF	Free Format	$x-$coordinate of the intersection of the baffle with the upper surface of the nacelle (Figure 19).
	XTIP	Free Format	$x-$coordinate of the nozzle trailing edge (Figure 19)
	YTIP	Free Format	$r-$coordinate of the nozzle trailing edge (Figure 19)
	XFAN	Free Format	$x-$coordinate of the input plane (Figure 19)
	XCBI	Free Format	$x-$coordinate of the point on the centerbody where the interior region ends (region I). This is now the same as the fan duct exit plane which has the $x-$coordinate XTIP. This entry is required by the format but is overridden internally (Figure 19).
	XCB	Free Format	$x-$coordinate of the trailing edge of the centerbody. The centerbody between XCBI and XCB is outside the exit plane (Figure 19).
	XCLII	Free Format	x−coordinate on the centerline where the region II ends; should exceed XCB. This defines the length of the extended jet (Figure 19).
5	NUPPER	Free Format	Number of intervals for upper nacelle surface spline (no. of points on the upper nacelle surface is NUPPER + 1) (Figure 18).

6	X(I) & Y(I)	Free Format	I=1, NUPPER + 1; Nacelle upper surface (x, r) coordinate pairs for spline fit; each coordinate pair should be input on a new line, i.e. there are NUPPER + 1 lines corresponding to this card block − each line representing a coordinate pair (Figure 19).
7	NINNER	Free Format	Number of intervals for inner nacelle surface spline (no. of points on the inner nacelle surface is NINNER + 1) (Figure 18)
8	X(I) & Y(I)	Free Format	I=1, NINNER + 1; Nacelle inner surface (x ,r) coordinate pairs for spline fit; each coordinate pair should be input on a new line, i.e. there are NINNER + 1 lines corresponding to this card block − each line representing a coordinate pair (Figure 19).
9	NELCEN	Free Format	Number of intervals for spline for entire centerbody (no. of centerbody points is NELCEN + 1); centerbody only, does not include centerline (Figure 18).
10	X(I) & Y(I)	Free Format	I=1, NELCEN + 1; Centerbody (x, r) coordinate pairs for spline fit; each coordinate pair should be input on a new line, i.e. there are NELCEN + 1 lines corresponding to this card block − each line representing a coordinate pair (Figure 19). *Note:* The number of (x, r) coordinate pairs for the centerbody does not include points on the centerline.
11	NY	I5	Number of elements along the duct radius in Region I (This is equal to the number of three−node line elements on the input plane). The input plane is the plane x = constant, at which the input duct modal amplitudes are specified (Figure 18).
	NX3	I5	Number of elements radially in Region III. Region III reaches from the end of the extended jet to the wave envelope region (Figure 18).
	NWEEL	I5	Number of wave envelope elements.
	NPRINT	I5	= 0, do not print nodal coordinate array = 1, print nodal coordinate array
	NDONT	I5	= 0, do not write output data file = 1, write output data file
	NCNTR	I5	= 0, there is no centerbody = 1, there is a centerbody
	NYT	I5	Number of angular increments in the locally polar mesh transition region; should not exceed NELT+NELC (Figure 19).
12	PCNT(I)	6F10.0	I = 1, NY; end node locations of the three−node line elements lying along the input plane. The node locations are given as fractions of the input plane width and starting from the intersection of the input plane and the lower surface of the nacelle. The first node therefore has a zero fractional distance and is not an input. If there are 5 line elements along the input plane then a typical input for this array would be 0.2, 0.4, 0.65, 0.88, 1.00 (Figure 19)
13	R3	F10.0	Upstream x intercept of circle bounding Region III in multiples of input plane duct radius.

13	R4	F10.0	Upstream x intercept of circle bounding wave envelope region (Region IV) in multiples of input plane duct radius.
14	DR1, DR2, DR3, etc.	6F10.0	Distance between the wave envelope circles given in terms of fractional distance between R3 and R4. All in terms of the upstream x intercepts. There are NWEEL of these. Three to eight layers is usually sufficient. The actual radius is Radius = R3 + DR*(R4 − R3).
15	MT	I5	Circumferential mode order (angular mode number), m
	NPOS	I5	No. of radial mode orders for circumferential mode order, m. Set NPOS=0 to skip the mode calculation. Do this if: 1) TFaNS version of radiation module is being run, or 2) Doing the radial mode order calculations in the Eversman Radiation Module is desired.
	VMACH	F10.0	Exterior flow Mach number (Positive for forward flight effect)
16	MSHIFT	I10	= 0, no shift of the nacelle geometry left or right = 1, shift of the nacelle geometry left or right
	XSHIFT	F10.0	Shift the nacelle geometry to help center the near field radiation for better performance of the wave envelope elements. Positive value of XSHIFT means shift to the left, i.e. shift towards the nozzle.
	EXPON	F10.0	Exponent which allows a uniform angular progression in the transition region to be made nonuniform = 1 for uniform distribution = < 1 if it is desirable to decrease element size as shear layer is approached = > 1 if it is desirable to increase element size as shear layer is approached Note: This feature is useful after checking the mesh resulting from the initial choice EXPON = 1.0. In most cases, EXPON <1.0 will turn out to be the best choice.

7.2.1.2 Input Running Option 2: Calculate Mesh only.

The first card is a header card allowing a maximum of 72 characters. It is formatted (18A4). It is not counted in the card sequence numbers defined below. Most of the data required in this option is also used in option 1.

All lengths are non−dimensionalized by the duct radius at the input plane.

Card	Variable	Format	Description
1	NLINU	I5	Number of three−node line elements to describe the upper surface of the nacelle
	NLINLI	I5	Number of three−node line elements to describe the lower surface of the nacelle
	NLINLC	I5	Number of three−node line elements to describe the centerbody, including the centerline in Region II
	NY	I5	Number of elements along the duct radius in Region I
	NX2	I5	Number of elements radially in Region II. Region II reaches from the exit plane to the end of the extended jet. NX2 is related to NLINLI by: NX2=NLINLC − NLINLI + 1 *Note:* Running Option 1 or using "AFTPRE.INP" provides values for NLINU, NLINLI, NLINLC, and NX2.
	NX3	I5	Number of elements radially in Region III. Region III extends from the end of the extended jet to the wave envelope region.
	NWEEL	I5	Number of wave envelope layers
	NPRINT	I5	= 0, do not write nodal coordinate array = 1, write nodal coordinate array
	NDONT	I5	= 0, do not write output data file = 1, write output data file
	NCNTR	I5	= 0, there is no centerbody = 1, there is a centerbody
	NCNTR1	I5	Sequence number of the first line element on the centerbody. It is the first element from the intersection of the centerbody and the input plane. Usually NCNTR1 = 1
	NCNTR2	I5	Sequence number of the last line element on the centerbody. It is the element at the intersection of the centerbody and the x−axis.
	NYT	I5	Number of angular increments in the locally polar mesh transition. Should not exceed NX2.
2	PCNT	6F10.0	I = 1, NY; Element end node locations from top to bottom in Region I. Fraction of Region I width. The first node at zero is not input.
3	X(I),Y(I), I=1,3	6F10.0	Coordinates of the three nodes on a line defining the upper nacelle surface. One line per element. There will be duplication of end point values. Sequenced from baffle aft. (NLINU records)

4	X(I),Y(I), I=1,3	6F10.0	Coordinates of the three nodes on a line defining the inner surface of the nozzle. One line per element. There will be duplication of end point values. Sequenced from input plane aft. (NLINLI records)
5	X(I),Y(I), I=1,3	6F10.0	Coordinates of the three nodes on a line defining the centerbody. One line per element. There will be duplication of end point values. Centerbody coordinates are defined on the centerbody and on the centerline in Region II. (NLINLC records)
14	R3	F10.0	Upstream *x* intercept of circle bounding Region III in multiples of input plane duct radius.
	R4	F10.0	Upstream *x* intercept of circle bounding wave envelope region (Region IV) in multiples of input plane duct radius.
15	DR1, DR2, DR3, etc.	6F10.0	Distance between the wave envelope circles given in terms of fractional distance between R3 and R4. All in terms of the upstream *x* intercepts. There are NWEEL of these. Three to eight layers is usually sufficient. The actual radius is Radius = R3 + DR*(R4 − R3).
9	MT	I5	Circumferential mode order (angular mode number), *m*
	NPOS	I5	No. of radial mode orders for circumferential mode order, *m* (see remarks about NPOS in Option 1)
	VMACH	F10.0	Exterior flow Mach number (Positive for forward flight effect)
10	MSHIFT	I10	= 0, no shift of the nacelle geometry left or right = 1, shift of the nacelle geometry left or right
	XSHIFT	F10.0	Shift the nacelle geometry to help center the near field radiation for better performance of the wave envelope elements. Positive value of XSHIFT means shift to the left, i.e. shift towards the nozzle.
	EXPON	F10.0	Exponent which allows a uniform angular progression in the transition region to be made nonuniform = 1 for uniform distribution = < 1 if it is desirable to decrease element size as shear layer is approached = > 1 if it is desirable to increase element size as shear layer is approached Note: This feature is useful after checking the mesh resulting from the initial choice EXPON = 1.0. In most cases, EXPON <1.0 will turn out to be the best choice.

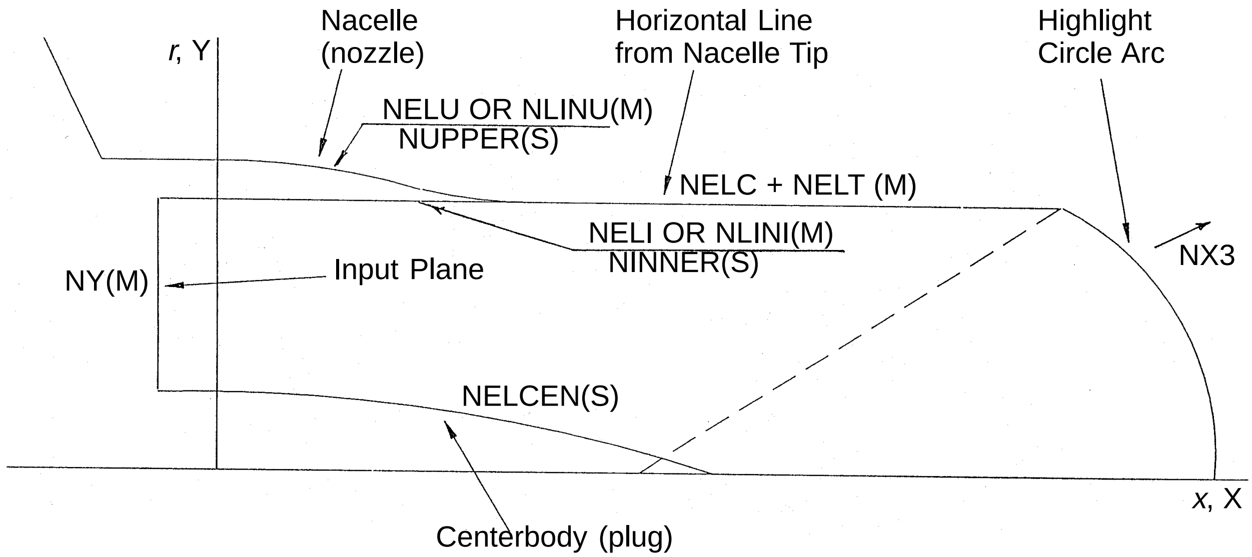


Figure 18: Aft computational domain showing input data related to numbers of mesh line elements, M, and spline intervals, S, on the various boundaries

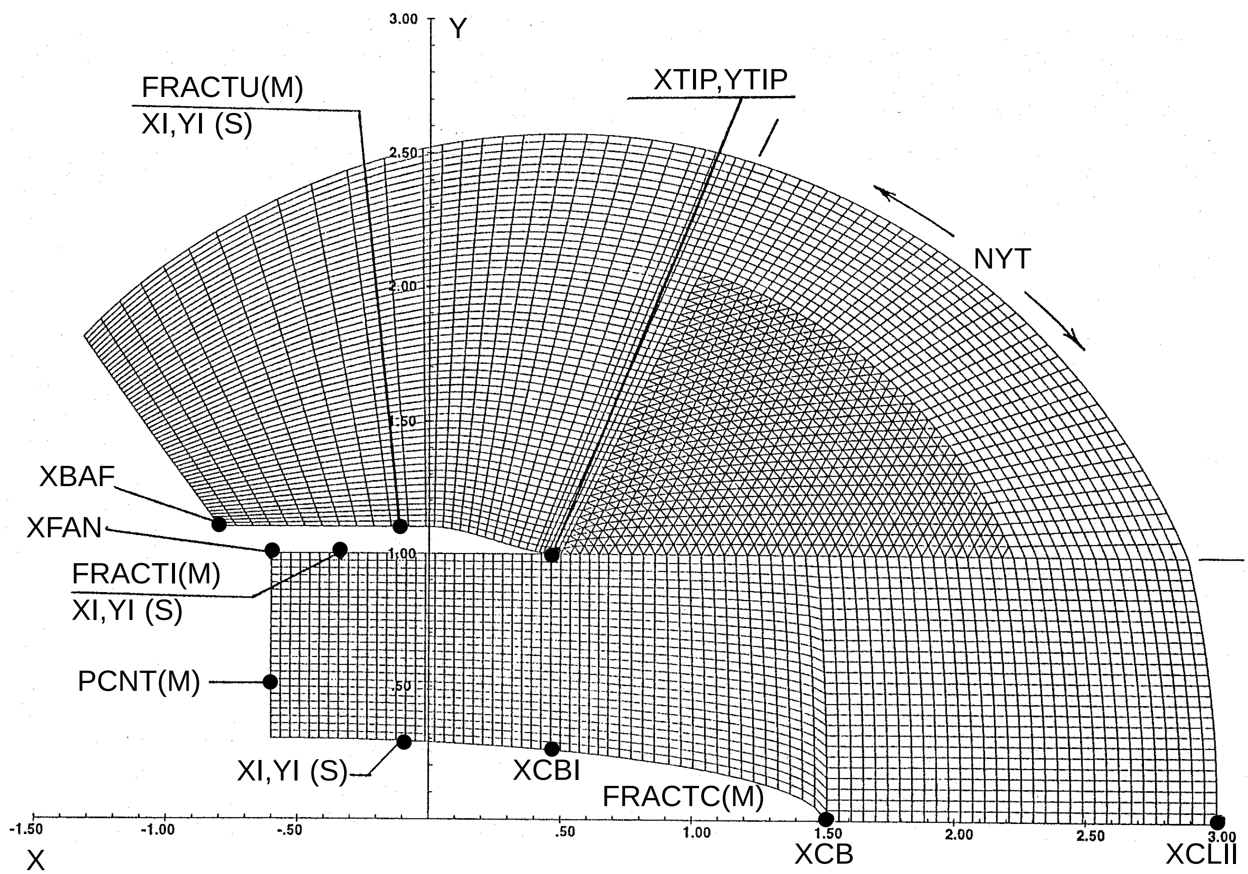


Figure 19: Aft fan duct mesh example showing key geometry points mesh line element end points, M, and spline intervals, S, on the various boundaries

7.2.2 Output Files

The mesh generation code, “aftmesh”, outputs the following files:

Output File	Output File Name	When Created	What is in it?
General Output	AFTMESH.OUT	Always	Spline fit results (if option 1 is run) List of element locations on each boundary Radiation element surface element topology and connectivity Total number of Elements and number of nodes
Mesh “restart” file	AFTMESH.DAT	Always	The mesh file used by all other parts of the radiation code
Postscript plotting file	AFTMESH.PS	Always	Mesh for the four regions split into three plots: • Region I only • Regions I, II, and III • Regions II, III, and IV These plots can be used to inspect the mesh for problems.
Option 2 input file	AFTMESH.INP	If option 1 is run	Input file which can be used to run option 2

7.2.3 Mesh Generation Hints

The general rule for the mesh density is that there should be about four to five elements per wave length in the principle direction of propagation in the regular mesh (within the duct, Region I, and in Regions II and III). The principle direction of propagation is axial in the duct and radial outside the duct. the number of elements per unit length can be related to the number of elements per wave length (accounting for wave length lengthening due to local convection) by the formula:

$$N_\lambda = \frac{2\pi}{\eta_r}(1 + M)N_R \tag{6}$$

or

$$N_R = \frac{\eta_r}{2\pi(1 + M)}N_\lambda \tag{7}$$

where:

N_λ = *number of elements per wave length*
N_R = *number of elements per unit length (a unit length is one input plane outer radius)*
η_r = *non dimensional frequency based on the reference speed of sound and the input plane outer radius.*
M = *local Mach number in flow which is positive downstream. the conservative choice for this would be the largest Mach number in the nozzle.*

For a required N_λ, this can be used to determine N_R. a good goal for N_λ is 5.

The mesh density across the duct and in the angular direction outside the duct should ideally be based on the same requirement, however results suggest that a much more coarse discretization provides reasonable results, and a good rule is to try to keep the element aspect ratio near 2.

For cases where the propagation is principally to the sideline (i.e., for nearly cut−off or cut−off modes) there can be significant reflection from the baffle. in these cases consideration should be given to sweeping the baffle back as far as possible consistent with computational size constraints.

7.2.4 Sample Input

7.2.4.1 Option 1: AFTPRE.INP

This sample mesh generation module input file for option 1 comes from the aft radiation code's "TFaNS1.5/aftrad.v4.0/testcases" subdirectory.

```
Sample test case – Option 1
  55    34   67    5
  -0.70000   1.91325  0.954783  0.727477   1.91325  4.405524
    4.5000
   85
 -2.0000          0.987486
 -1.5000          0.987486
-1.40000          0.987486
-1.25000          0.987486
-1.20000          0.987486
-1.15000          0.987486
-1.13000          0.987486
-1.12130          0.987486
-1.11986          0.995125
-1.11538           1.00312
-1.10764           1.01144
-1.09641           1.02007
-1.08152           1.02896
-1.06281           1.03808
-1.04017           1.04736
-1.01353           1.05676
-.982877           1.06621
-.948270           1.07564
-.909817           1.08498
-.867695           1.09415
-.822142           1.10307
-.773458           1.11169
-.721992           1.11993
-.668140           1.12771
-.612333           1.13500
-.555023           1.14174
-.496673           1.14789
-.437749           1.15343
-.378701           1.15834
-.319959           1.16260
-.261923           1.16622
-.204953           1.16921
```

-.149371	1.17160
-.954489E-01	1.17339
-.434179E-01	1.17463
0.653934E-02	1.17535
0.542832E-01	1.17558
0.946869E-01	1.17549
0.134986	1.17522
0.175184	1.17477
0.215279	1.17414
0.255271	1.17333
0.295160	1.17233
0.334947	1.17116
0.374631	1.16981
0.414212	1.16828
0.453691	1.16657
0.493067	1.16467
0.532340	1.16260
0.571511	1.16035
0.610578	1.15792
0.649543	1.15530
0.688406	1.15251
0.727165	1.14953
0.765822	1.14638
0.804377	1.14305
0.842828	1.13953
0.881176	1.13584
0.919423	1.13196
0.957567	1.12791
0.995607	1.12367
1.03355	1.11925
1.07138	1.11466
1.10911	1.10988
1.14674	1.10493
1.18427	1.09979
1.22169	1.09447
1.25902	1.08897
1.29624	1.08330
1.33335	1.07744
1.37037	1.07140
1.40728	1.06518
1.44409	1.05878
1.48079	1.05221
1.51739	1.04545
1.55389	1.03851
1.59029	1.03139
1.62659	1.02409
1.66278	1.01661
1.69887	1.00895
1.73486	1.00111
1.77074	0.993088
1.80652	0.984886

1.84220	0.976506
1.87777	0.965944
1.91325	0.954783
153	
–1.12130	0.987486
–1.12060	0.980156
–1.11845	0.972659
–1.11473	0.965060
–1.10938	0.957433
–1.10233	0.949861
–1.09358	0.942430
–1.08315	0.935232
–1.07109	0.928354
–1.05751	0.921883
–1.04255	0.915899
–1.02638	0.910468
–1.00918	0.905645
–.991185	0.901472
–.972609	0.897972
–.953677	0.895154
–.934610	0.893011
–.915613	0.891525
–.896870	0.890663
–.878545	0.890386
–.854149	0.890570
–.829753	0.891121
–.805357	0.892034
–.780960	0.893299
–.756564	0.894908
–.732168	0.896846
–.707772	0.899094
–.683376	0.901634
–.658979	0.904442
–.634584	0.907495
–.610188	0.910764
–.585792	0.914222
–.561398	0.917838
–.537002	0.921579
–.512607	0.925413
–.488211	0.929306
–.463817	0.933223
–.439421	0.937130
–.415026	0.940992
–.390630	0.944775
–.366235	0.948446
–.341839	0.951973
–.317443	0.955324
–.293048	0.958469
–.268651	0.961381
–.244256	0.964034
–.219859	0.966404

-.195463	0.968472
-.171067	0.970218
-.153956	0.971154
-.136828	0.971726
-.123227	0.971965
-.109633	0.972327
-.890112E-01	0.973636
-.684200E-01	0.975544
-.513548E-01	0.977170
-.342683E-01	0.978372
-.171430E-01	0.978837
0.	0.978852
0.171386E-01	0.978757
0.342736E-01	0.978497
0.514034E-01	0.977920
0.685057E-01	0.976882
0.855594E-01	0.975291
0.102588	0.973272
0.119626	0.971195
0.136719	0.970205
0.152346	0.969866
0.167999	0.970135
0.183662	0.970764
0.199320	0.971513
0.214967	0.972313
0.230601	0.973193
0.246219	0.974186
0.261821	0.975326
0.277405	0.976645
0.292968	0.978175
0.308511	0.979926
0.324036	0.981873
0.339544	0.983988
0.355039	0.986243
0.370521	0.988610
0.385992	0.991060
0.401458	0.993556
0.416924	0.996032
0.432399	0.998414
0.447891	1.00063
0.463409	1.00260
0.478962	1.00427
0.494554	1.00557
0.510175	1.00657
0.525815	1.00732
0.541462	1.00790
0.557110	1.00832
0.572760	1.00856
0.588409	1.00857
0.604488	1.00832
0.620562	1.00781

0.636629	1.00705
0.652685	1.00605
0.668724	1.00481
0.684743	1.00333
0.700759	1.00182
0.716787	1.00054
0.732844	0.999729
0.747309	0.999261
0.761771	0.998778
0.776234	0.998328
0.790703	0.997955
0.805236	0.997757
0.819905	0.997782
0.834731	0.998010
0.849740	0.998425
0.864954	0.999008
0.880398	0.999742
0.896095	1.00061
0.912068	1.00159
0.928341	1.00267
0.944938	1.00382
0.961882	1.00504
0.979198	1.00630
0.996907	1.00759
1.01503	1.00888
1.03360	1.01016
1.05264	1.01142
1.07216	1.01262
1.09220	1.01377
1.11277	1.01483
1.13391	1.01579
1.15562	1.01663
1.17795	1.01733
1.20090	1.01789
1.22451	1.01826
1.24879	1.01845
1.27378	1.01844
1.29950	1.01819
1.32596	1.01771
1.35319	1.01696
1.38122	1.01593
1.41007	1.01460
1.43976	1.01296
1.47032	1.01099
1.50177	1.00866
1.53414	1.00597
1.56744	1.00288
1.60170	0.999398
1.63695	0.995489
1.67321	0.991139
1.71050	0.986331

1.74884	0.981047
1.78826	0.975267
1.82879	0.968976
1.87044	0.962153
1.91325	0.954783
136	
0.330591	0.490583
0.331475	0.493323
0.332359	0.494517
0.334127	0.496417
0.338546	0.499776
0.344734	0.502825
0.353573	0.506140
0.362413	0.508527
0.371252	0.510427
0.380091	0.511886
0.393767	0.512933
0.404318	0.513565
0.419868	0.513565
0.441967	0.513565
0.464065	0.513565
0.495003	0.513565
0.529476	0.513565
0.556878	0.513565
0.582689	0.513565
0.598776	0.515245
0.616455	0.519664
0.634134	0.526117
0.651812	0.533807
0.669491	0.541586
0.687170	0.548923
0.704848	0.555287
0.727124	0.561298
0.740206	0.563596
0.757885	0.565629
0.775563	0.566955
0.793242	0.568016
0.810920	0.569165
0.828599	0.570225
0.846278	0.571375
0.863956	0.572347
0.881635	0.573319
0.899314	0.574115
0.916992	0.574910
0.934671	0.575617
0.952350	0.576325
0.970028	0.577032
0.987707	0.577827
1.00539	0.578534
1.02306	0.579418
1.04074	0.580391

1.05842	0.581451
1.07610	0.582600
1.09378	0.583926
1.11146	0.585429
1.12914	0.586932
1.14682	0.588611
1.16449	0.590379
1.18217	0.592147
1.19985	0.594092
1.21753	0.596036
1.23521	0.598069
1.25289	0.600191
1.27057	0.602312
1.28824	0.604434
1.30043	0.605551
1.32426	0.608618
1.34809	0.611647
1.37193	0.614619
1.39577	0.617513
1.41961	0.620309
1.44347	0.622986
1.46732	0.625522
1.49119	0.627901
1.51507	0.630099
1.53896	0.632098
1.56286	0.633877
1.58677	0.635415
1.61070	0.636692
1.63464	0.637688
1.65860	0.638383
1.68257	0.638756
1.70657	0.638787
1.73058	0.638455
1.75461	0.637741
1.77867	0.636625
1.80275	0.635085
1.82686	0.633101
1.85098	0.630654
1.87514	0.627723
1.89932	0.624261
1.92329	0.619243
1.94703	0.613325
1.97077	0.607406
1.99451	0.601488
2.01824	0.595570
2.04198	0.589652
2.06572	0.583733
2.08945	0.577815
2.11319	0.571896
2.13693	0.565978
2.16067	0.560059

```
 2.18441         0.554141
 2.21984         0.548023
 2.26293         0.545387
 2.29823         0.545387
 2.38662         0.545387
 2.47501         0.545387
 2.56341         0.545387
 2.65180         0.545387
 2.74019         0.545387
 2.82859         0.545387
 2.91698         0.545387
 3.00537         0.545387
 3.09377         0.545387
 3.18216         0.545387
 3.24863         0.545387
 3.31475         0.545387
 3.32427 0.54530
 3.34329 0.54464
 3.36228 0.54331
 3.38122 0.54132
 3.40007 0.53867
 3.41881 0.53537
 3.43744 0.53141
 3.45591 0.52680
 3.47421 0.52156
 3.49231 0.51567
 3.51020 0.50916
 3.52785 0.50203
 3.54524 0.49429
 3.56235 0.48594
 3.57916 0.47701
 3.58744 0.47232
 3.63744 0.44345
 3.68744 0.41458
 3.80000 0.34960
 3.90000 0.29186
 4.00000 0.23413
     4.1 0.17639
     4.2 0.11866
     4.3 0.06092
4.405524 0.00000
   33   55    7    0    1    1   40
 0.0300000 0.0600000 0.0900000 0.1200000 0.1500000 0.1800000
 0.2100000 0.2400000 0.2700000 0.3000000 0.3300000 0.3600000
 0.3900000 0.4200000 0.4500000 0.4800000 0.5100000 0.5400000
 0.5700000 0.6000000 0.6300000 0.6600000 0.6900000 0.7200000
 0.7500000 0.7800000 0.8100000 0.8400000 0.8700000 0.9000000
 0.9300000 0.9650000 1.0000000
   4.30000   9.72327
     0.025      0.07      0.14      0.25      0.45      0.65
     1.000
```

```
   10    0       0.1
         1    1.2500    .90000
```

7.2.4.2 Option 2: AFTMESH.INP

This sample mesh generation module input file for option 2 was generated by the input file shown above for option 1.

```
Sample Input file – Option 2
   55   34  106   33   72   55    7    0    1    1    1  104   40
   0.03000   0.06000   0.09000   0.12000   0.15000   0.18000
   0.21000   0.24000   0.27000   0.30000   0.33000   0.36000
   0.39000   0.42000   0.45000   0.48000   0.51000   0.54000
   0.57000   0.60000   0.63000   0.66000   0.69000   0.72000
   0.75000   0.78000   0.81000   0.84000   0.87000   0.90000
   0.93000   0.96500   1.00000
  -1.95000   1.12320  -1.89782   1.13045  -1.84555   1.13705
  -1.84555   1.13705  -1.79321   1.14304  -1.74081   1.14847
  -1.74081   1.14847  -1.68836   1.15338  -1.63586   1.15778
  -1.63586   1.15778  -1.58333   1.16168  -1.53076   1.16511
  -1.53076   1.16511  -1.49131   1.16736  -1.45185   1.16936
  -1.45185   1.16936  -1.42554   1.17054  -1.39922   1.17160
  -1.39922   1.17160  -1.37289   1.17254  -1.34656   1.17336
  -1.34656   1.17336  -1.32023   1.17405  -1.29390   1.17462
  -1.29390   1.17462  -1.26756   1.17506  -1.24122   1.17537
  -1.24122   1.17537  -1.21488   1.17554  -1.18854   1.17558
  -1.18854   1.17558  -1.16220   1.17552  -1.13586   1.17538
  -1.13586   1.17538  -1.10952   1.17517  -1.08318   1.17488
  -1.08318   1.17488  -1.05684   1.17451  -1.03051   1.17406
  -1.03051   1.17406  -1.00417   1.17354  -0.97784   1.17293
  -0.97784   1.17293  -0.95151   1.17224  -0.92518   1.17147
  -0.92518   1.17147  -0.89885   1.17063  -0.87252   1.16971
  -0.87252   1.16971  -0.84620   1.16870  -0.81988   1.16761
  -0.81988   1.16761  -0.79357   1.16644  -0.76726   1.16519
  -0.76726   1.16519  -0.74095   1.16385  -0.71465   1.16243
  -0.71465   1.16243  -0.68835   1.16093  -0.66206   1.15935
  -0.66206   1.15935  -0.64234   1.15811  -0.62263   1.15681
  -0.62263   1.15681  -0.60292   1.15547  -0.58321   1.15408
  -0.58321   1.15408  -0.56351   1.15265  -0.54381   1.15117
  -0.54381   1.15117  -0.52411   1.14963  -0.50442   1.14805
  -0.50442   1.14805  -0.48473   1.14643  -0.46505   1.14475
  -0.46505   1.14475  -0.44537   1.14303  -0.42569   1.14125
  -0.42569   1.14125  -0.40602   1.13943  -0.38635   1.13755
  -0.38635   1.13755  -0.36669   1.13563  -0.34704   1.13365
  -0.34704   1.13365  -0.32738   1.13163  -0.30774   1.12956
  -0.30774   1.12956  -0.28810   1.12744  -0.26846   1.12526
  -0.26846   1.12526  -0.24883   1.12303  -0.22921   1.12076
  -0.22921   1.12076  -0.20959   1.11843  -0.18998   1.11606
  -0.18998   1.11606  -0.17037   1.11363  -0.15077   1.11115
  -0.15077   1.11115  -0.13118   1.10862  -0.11159   1.10604
  -0.11159   1.10604  -0.09201   1.10341  -0.07244   1.10072
  -0.07244   1.10072  -0.05288   1.09798  -0.03332   1.09519
```

−0.03332	1.09519	−0.01377	1.09235	0.00577	1.08946
0.00577	1.08946	0.02531	1.08651	0.04484	1.08352
0.04484	1.08352	0.06435	1.08046	0.08386	1.07736
0.08386	1.07736	0.10337	1.07420	0.12286	1.07099
0.12286	1.07099	0.14234	1.06772	0.16182	1.06440
0.16182	1.06440	0.18128	1.06103	0.20074	1.05760
0.20074	1.05760	0.22019	1.05413	0.23962	1.05060
0.23962	1.05060	0.25905	1.04701	0.27847	1.04337
0.27847	1.04337	0.29787	1.03967	0.31727	1.03592
0.31727	1.03592	0.33666	1.03211	0.35603	1.02825
0.35603	1.02825	0.37539	1.02433	0.39475	1.02036
0.39475	1.02036	0.41409	1.01634	0.43342	1.01225
0.43342	1.01225	0.45273	1.00812	0.47204	1.00392
0.47204	1.00392	0.49133	0.99968	0.51062	0.99539
0.51062	0.99539	0.52989	0.99104	0.54914	0.98662
0.54914	0.98662	0.56838	0.98211	0.58756	0.97741
0.58756	0.97741	0.60030	0.97409	0.61299	0.97057
0.61299	0.97057	0.62561	0.96683	0.63818	0.96291
0.63818	0.96291	0.65073	0.95888	0.66325	0.95478
−0.52252	0.99995	−0.50468	0.99934	−0.48683	0.99873
−0.48683	0.99873	−0.46899	0.99819	−0.45114	0.99782
−0.45114	0.99782	−0.43328	0.99776	−0.41543	0.99801
−0.41543	0.99801	−0.39758	0.99852	−0.37974	0.99925
−0.37974	0.99925	−0.36191	1.00015	−0.34409	1.00120
−0.34409	1.00120	−0.32627	1.00236	−0.30845	1.00358
−0.30845	1.00358	−0.29065	1.00486	−0.27284	1.00615
−0.27284	1.00615	−0.25503	1.00745	−0.23722	1.00872
−0.23722	1.00872	−0.21941	1.00996	−0.20159	1.01114
−0.20159	1.01114	−0.18377	1.01227	−0.16595	1.01331
−0.16595	1.01331	−0.14812	1.01428	−0.13029	1.01516
−0.13029	1.01516	−0.11245	1.01594	−0.09461	1.01662
−0.09461	1.01662	−0.07676	1.01719	−0.05891	1.01767
−0.05891	1.01767	−0.04106	1.01804	−0.02321	1.01829
−0.02321	1.01829	−0.00535	1.01843	0.01250	1.01847
0.01250	1.01847	0.03036	1.01840	0.04821	1.01821
0.04821	1.01821	0.06606	1.01792	0.08391	1.01752
0.08391	1.01752	0.10176	1.01701	0.11960	1.01639
0.11960	1.01639	0.13744	1.01567	0.15528	1.01484
0.15528	1.01484	0.17311	1.01391	0.19094	1.01289
0.19094	1.01289	0.20876	1.01177	0.22657	1.01055
0.22657	1.01055	0.24438	1.00923	0.26218	1.00783
0.26218	1.00783	0.27997	1.00633	0.29775	1.00474
0.29775	1.00474	0.31553	1.00307	0.33330	1.00131
0.33330	1.00131	0.35106	0.99947	0.36881	0.99754
0.36881	0.99754	0.38655	0.99554	0.40428	0.99345
0.40428	0.99345	0.42201	0.99129	0.43972	0.98905
0.43972	0.98905	0.45742	0.98674	0.47512	0.98436
0.47512	0.98436	0.49280	0.98190	0.51048	0.97938
0.51048	0.97938	0.52815	0.97678	0.54580	0.97412
0.54580	0.97412	0.56051	0.97186	0.57521	0.96955
0.57521	0.96955	0.58990	0.96719	0.60458	0.96480

0.60458	0.96480	0.61926	0.96235	0.63393	0.95986
0.63393	0.95986	0.64859	0.95733	0.66325	0.95478
−0.52252	0.56137	−0.50474	0.56428	−0.48695	0.56607
−0.48695	0.56607	−0.46916	0.56728	−0.45138	0.56836
−0.45138	0.56836	−0.43359	0.56950	−0.41580	0.57059
−0.41580	0.57059	−0.39802	0.57170	−0.38023	0.57267
−0.38023	0.57267	−0.36244	0.57360	−0.34466	0.57439
−0.34466	0.57439	−0.32687	0.57516	−0.30908	0.57587
−0.30908	0.57587	−0.29130	0.57657	−0.27351	0.57732
−0.27351	0.57732	−0.25572	0.57809	−0.23794	0.57885
−0.23794	0.57885	−0.22015	0.57978	−0.20236	0.58079
−0.20236	0.58079	−0.18458	0.58189	−0.16679	0.58311
−0.16679	0.58311	−0.14900	0.58453	−0.13122	0.58604
−0.13122	0.58604	−0.11343	0.58761	−0.09564	0.58937
−0.09564	0.58937	−0.07786	0.59113	−0.06007	0.59299
−0.06007	0.59299	−0.04228	0.59496	−0.02450	0.59694
−0.02450	0.59694	−0.00671	0.59904	0.01107	0.60116
0.01107	0.60116	0.02886	0.60336	0.04665	0.60520
0.04665	0.60520	0.06443	0.60726	0.08222	0.60967
0.08222	0.60967	0.10001	0.61189	0.11779	0.61411
0.11779	0.61411	0.13558	0.61629	0.15337	0.61842
0.15337	0.61842	0.17115	0.62049	0.18894	0.62249
0.18894	0.62249	0.20673	0.62441	0.22451	0.62626
0.22451	0.62626	0.24230	0.62801	0.26009	0.62966
0.26009	0.62966	0.27787	0.63120	0.29566	0.63262
0.29566	0.63262	0.31345	0.63392	0.33123	0.63508
0.33123	0.63508	0.34902	0.63610	0.36681	0.63697
0.36681	0.63697	0.38459	0.63769	0.40238	0.63823
0.40238	0.63823	0.42017	0.63860	0.43795	0.63879
0.43795	0.63879	0.45574	0.63879	0.47353	0.63859
0.47353	0.63859	0.49131	0.63818	0.50910	0.63756
0.50910	0.63756	0.52689	0.63672	0.54467	0.63565
0.54467	0.63565	0.55949	0.63457	0.57432	0.63333
0.57432	0.63333	0.58914	0.63192	0.60396	0.63031
0.60396	0.63031	0.61878	0.62852	0.63361	0.62663
0.63361	0.62663	0.64843	0.62441	0.66325	0.62153
0.66325	0.62153	0.67791	0.61813	0.69257	0.61445
0.69257	0.61445	0.70723	0.61077	0.72189	0.60713
0.72189	0.60713	0.73656	0.60347	0.75122	0.59981
0.75122	0.59981	0.76588	0.59616	0.78054	0.59250
0.78054	0.59250	0.79520	0.58885	0.80986	0.58519
0.80986	0.58519	0.82807	0.58065	0.84628	0.57611
0.84628	0.57611	0.86449	0.57157	0.88270	0.56703
0.88270	0.56703	0.90091	0.56252	0.91912	0.55789
0.91912	0.55789	0.93733	0.55349	0.95554	0.55002
0.95554	0.55002	0.97375	0.54759	0.99196	0.54613
0.99196	0.54613	1.01017	0.54544	1.02838	0.54528
1.02838	0.54528	1.04659	0.54538	1.06480	0.54546
1.06480	0.54546	1.08301	0.54548	1.10122	0.54546
1.10122	0.54546	1.11943	0.54542	1.13764	0.54539
1.13764	0.54539	1.15585	0.54537	1.17406	0.54536

1.17406	0.54536	1.19227	0.54537	1.21048	0.54538
1.21048	0.54538	1.22869	0.54539	1.24690	0.54539
1.24690	0.54539	1.26511	0.54539	1.28332	0.54539
1.28332	0.54539	1.30153	0.54539	1.31974	0.54539
1.31974	0.54539	1.33795	0.54539	1.35616	0.54539
1.35616	0.54539	1.37437	0.54539	1.39258	0.54539
1.39258	0.54539	1.41079	0.54539	1.42900	0.54539
1.42900	0.54539	1.44721	0.54539	1.46542	0.54539
1.46542	0.54539	1.48363	0.54539	1.50184	0.54539
1.50184	0.54539	1.52005	0.54539	1.53826	0.54539
1.53826	0.54539	1.55647	0.54539	1.57468	0.54539
1.57468	0.54539	1.59289	0.54539	1.61110	0.54539
1.61110	0.54539	1.62931	0.54539	1.64752	0.54539
1.64752	0.54539	1.66573	0.54539	1.68394	0.54539
1.68394	0.54539	1.70215	0.54539	1.72036	0.54539
1.72036	0.54539	1.73857	0.54539	1.75678	0.54539
1.75678	0.54539	1.77499	0.54539	1.79320	0.54539
1.79320	0.54539	1.81141	0.54539	1.82962	0.54539
1.82962	0.54539	1.84783	0.54539	1.86604	0.54539
1.86604	0.54539	1.88425	0.54539	1.90246	0.54539
1.90246	0.54539	1.92067	0.54539	1.93888	0.54538
1.93888	0.54538	1.95709	0.54537	1.97530	0.54537
1.97530	0.54537	1.99351	0.54538	2.01172	0.54541
2.01172	0.54541	2.02993	0.54544	2.04814	0.54544
2.04814	0.54544	2.06635	0.54538	2.08456	0.54503
2.08456	0.54503	2.10277	0.54406	2.12098	0.54248
2.12098	0.54248	2.13919	0.54028	2.15740	0.53746
2.15740	0.53746	2.17561	0.53400	2.19382	0.52989
2.19382	0.52989	2.21203	0.52512	2.23024	0.51968
2.23024	0.51968	2.24845	0.51351	2.26666	0.50663
2.26666	0.50663	2.28487	0.49899	2.30308	0.49055
2.30308	0.49055	2.32129	0.48129	2.33950	0.47114
2.33950	0.47114	2.35771	0.46066	2.37592	0.45012
2.37592	0.45012	2.39413	0.43958	2.41234	0.42906
2.41234	0.42906	2.43055	0.41855	2.44876	0.40805
2.44876	0.40805	2.46697	0.39754	2.48518	0.38703
2.48518	0.38703	2.50339	0.37652	2.52160	0.36600
2.52160	0.36600	2.53981	0.35548	2.55802	0.34497
2.55802	0.34497	2.57623	0.33445	2.59444	0.32394
2.59444	0.32394	2.61265	0.31342	2.63086	0.30291
2.63086	0.30291	2.64907	0.29240	2.66728	0.28188
2.66728	0.28188	2.68549	0.27137	2.70370	0.26086
2.70370	0.26086	2.72191	0.25035	2.74012	0.23983
2.74012	0.23983	2.75833	0.22932	2.77654	0.21881
2.77654	0.21881	2.79475	0.20829	2.81296	0.19778
2.81296	0.19778	2.83117	0.18726	2.84938	0.17675
2.84938	0.17675	2.86759	0.16623	2.88580	0.15572
2.88580	0.15572	2.90401	0.14521	2.92222	0.13470
2.92222	0.13470	2.94043	0.12418	2.95864	0.11367
2.95864	0.11367	2.97685	0.10316	2.99506	0.09264
2.99506	0.09264	3.01327	0.08213	3.03148	0.07161

```
3.03148   0.07161   3.04969   0.06110   3.06790   0.05059
3.06790   0.05059   3.08611   0.04007   3.10432   0.02956
3.10432   0.02956   3.12253   0.01905   3.14074   0.00853
3.14074   0.00853   3.15895   0.00000   3.17716   0.00000
3.17716   0.00000   3.19537   0.00000   3.21358   0.00000
3.21358   0.00000   3.23179   0.00000   3.25000   0.00000
4.30000   9.72327
0.02500   0.07000   0.14000   0.25000   0.45000   0.65000
1.00000
10    0   0.10000
      1   1.25000   0.90000
```

7.3 POTENTIAL FLOW CODE

7.3.1 Input Format

The steady mean flow problem on the finite element mesh is solved by the “aftflow” or “aftflow10” codes. “aftflow” outputs temporary files to the user’s hard drive. “aftflow10” has been successfully used on Sun SPARC workstations at Pratt & Whitney and outputs temporary files to the “/tmp” subdirectory. The following files are input:

Input File	Source
AFTFLOW.INP	User Generated input file (see below)
AFTMESH.DAT	Mesh “restart” file created by “aftmesh” (See Section 7.2.2)

AFTFLOW.INP has only one card and the input data is formatted. The card is a maximum of 80 characters. Except for special cases, this file will probably not need to be changed from one run to the next. The input variables should be placed in AFTFLOW.INP in the sequence described below:

Card	Variable	Format	Description
1	NTYPE	I5	= 1, calculates the mean flow velocity potential for flow from negative infinity around the shear layer and into the blank exhaust duct = 2, calculates the velocity potential for the exhaust duct flow alone = 3, calculates both cases sequentially and writes the solution vector to disk for use by the the aft radiation code. This is the usual choice.
	PRINT1	I5	(Not Used) ≠ 0, beginning row and column of the assembled stiffness matrix to be printed = 0, do not print
	PRINT2	I5	(Not Used) ≠ 0, final row and column of the assembled stiffness matrix to be printed = 0, do not print
	NPLOT	I5	(Not Used) = 0, contour plotting routine bypassed matrix to be printed = 1, plot contour level curves for the solution vector
	NPRINT	I5	= 0, do not print nodal coordinate array = 1, print nodal coordinate array

7.3.2 Output Files

The Potential Flow Code, “aftflow” or “aftflow10”, outputs the following files:

Output File	**Output File Name**	**When Created**	**What is in it?**
General Output	AFTFLOW.OUT	Always	Information about the case being run. Solution for the two mean flow calculations.
Potential flow field “restart” file	AFTFLOW.DAT	Always	The nodal mean flow velocity potential required by “aftrad”, “aftrad10”, “aftrad3d” or “aftrad3d10”
Postscript plotting file	AFTFLOW.PS	Always	Contour Plots of potential flow field for the two separate potential flow calculations.
Temporary work files	fort.1 fort.2 fort.3 fort.4 fort.8 Temporary files 15, 16, 17, 18	Always	In “aftflow” these files are output to user’s computer. In “aftflow10” (except for files 15, 16, 17, 18) these files are output to the “/tmp” subdirectory on the user’s computer.

7.3.3 Sample Input

This sample potential flow module input file comes from the aft radiation code’s “TFaNS1.5/aftrad.v4.0/testcases” subdirectory.

```
    3    0   10    1    0
```

7.4 EVERSMAN RADIATION MODULE

7.4.1 Input Format

Input data files for the Eversman aft radiation code, "aftrad" or "aftrad10", are shown below:

Input File	Source
AFTRAD.INP	User Generated input file (see below)
AFTMESH.DAT	Mesh "restart" file created by "aftmesh" (See Section 7.2.2)
AFTFLOW.DAT	Potential flow "restart" file created by "aftflow" or "aftflow10" (See Section 7.3.2)

"aftrad" is run if temporary files can be placed on the user's computer. "aftrad10" has worked on Sun SPARC workstations at Pratt & Whitney where this code will place all temporary files in the "/tmp" subdirectory.

The input data has been structured into cards. Each card of data begins on a new line and the input data is formatted. The acoustic radiation program is capable of running multiple cases. It contains the data for all the cases with an alphanumeric input separating the data for any two cases which determines whether the case is to be run or not.

The code has two options which will output files for post processing:

- NPOST = 1 will output a postscript file containing eight radiation plots.
- NPOST = 2 produces the data file for contour plotting using alternative contour plotting software.

The input format for the user generated input file, "AFTRAD.INP", is given below:

Card	Variable	Format	Description
1	HDR(I)	14A4	I = 1,14 (Character*4); This card is used for two purposes: • It is the title card for each case or • It is the last card in the file where HDR(1) = 'STOP'. When STOP is placed in the first four columns, the program stops execution. Thus this card also controls the running of multiple cases by determining where the program will stop.
2	NSYM	I10	= 0, Two Dimensional duct = 1, circular or annular duct
	ETAR	F10.5	Nondimensional frequency of the sound source ($\eta_r = \omega R / c_r$) ω = fan rotational speed in rad/sec R = outer duct radius at the input plane c_r = freestream speed of sound outside the nacelle
	NIMP	I10	= 1, acoustic liner is given by specifying admittances = 2, acoustic liner is given by specifying impedances
	MTHETA	I5	Circumferential mode order (angular mode number), m

2	NPOS	I5	No. of radial mode orders for circumferential mode order, m. Set NPOS = 0 here if NPOS > 0 during the mesh calculation in “aftmesh”. This means radial mode calculations were done in “aftmesh”. Set NPOS > 0 here if NPOS = 0 during the mesh calculation in “aftmesh”. This means that MTHETA and NPOS are required in “aftrad” to do the radial mode calculations since they were not done in “aftmesh”.
3	PRINT1	I5	(Not Used) $\neq$ 0, Beginning row and column in stiffness matrices printed = 0, Beginning row and column in stiffness matrices not printed
	PRINT2	I5	(Not Used) $\neq$ 0, Final row and column in stiffness matrices printed = 0, Final row and column in stiffness matrices not printed
	NPLOT	I5	(Not Used) > 0, level curves for the solution vector plotted = 0, plotting routine bypassed
	NCONT	I5	Number of contours to be plotted (Postscript plots only)
	CMAXO	F10.5	Value of maximum contour level (Postscript plots only)
	CMINO	F10.5	Value of minimum contour level (Postscript plots only)
4	ZAI(I)	6F10.5	I = 1, NPOS; complex incident modal amplitudes non−dimensionalized by (RHOFS)(CFS)^2, (complex: real and imaginary parts, three per card). 2 x NPOS numbers need to be input.
5	NLINO	I5	Number of acoustically lined elements on the duct outer surface, see Figure 15 (if NLINO =0 there is no lining and ZADMO need not be input)
	MBEGO	I5	Element number (counted along the duct outer surface from the input plane) on which the lining begins, see Figure 15.
	NLINI	I5	Number of acoustically lined elements on the duct inner surface, see Figure 15 (if NLINI =0 there is no lining and ZADMI need not be input)
	MBEGI	I5	Element number (counted along the duct inner surface from the input plane) on which the lining begins, see Figure 15.
6	ZADMO(I,J)	6F10.5	Input only if NLINO > 0; This parameter is specified at the frequency being run and is non−dimensionalized by the local density x acoustic speed. I = 1, NLINO, J = 1,3; If NIMP = 1, input admittances in each treated node of an element on the duct outer surface (complex: real and imaginary parts, one element per card) If NIMP = 2, input impedances in each treated node of an element on the duct outer surface (complex: real and imaginary parts, one element per card)

7	ZADMI(I,J)	6F10.5	Input only if NLINI > 0; This parameter is specified at the frequency being run and is non−dimensionalized by the local density x acoustic speed. I = 1, NLINI, J = 1,3; If NIMP = 1, input admittances in each treated node of an element on the duct inner surface (complex: real and imaginary parts, one element per card) If NIMP = 2, input impedances in each treated node of an element on the duct inner surface (complex: real and imaginary parts, one element per card)
8	NPOST	I5	= 1, Acoustic pressures for contour plotting are calculated at the nodes and the postscript plotting routines are used for pressure contour plotting. = 2, Acoustic pressures for contour plotting are calculated at the Gauss points in the elements and a data file for a suitable alternative contour plotter (e.g. TECPLOT) is produced.
9	VMACHI	F10.5	Average compressible exhaust Mach number at input plane. (Positive for exhaust flow and based on local speed of sound)
	CFS	F10.5	Free stream (far from the nacelle) speed of sound (ft/sec)
	RHOFS	F10.5	Free stream (far from the nacelle) density ($lb-s^2/ft^4$)
10	XSHIFT	F10.5	Axial shift of the origin non−dimensionalized by the input plane outer duct radius. Positive value of XSHIFT means shift to the left, i.e. shift towards the nozzle (Use the opposite sign as in the mesh generation routine to get back to the original origin) This parameter determines where the origin of the measurement arc will be placed. *Note:* It is important to assure that the shift, XSHIFT, and arc (arc radius = RM) are not so large that some of it is outside the grid. If the radius is too large, it will be detected and the maximum permissible radius will be used. Similarly, be sure that the measurement radius is not so small that the arc is in the conventional element region. Post processing assumes the directivity is to be obtained in the wave envelope region.
	RM	F10.5	Measurement arc radius non−dimensionalized by the input plane duct radius (see note above).
11	NBAFL	I10	= 0, The baffle admittance option is not used = 1, The baffle admittance option is used
	ZAB	2F10.5	Admittance on the baffle used to produce absorption non−dimensionalized by RHOFS*CFS, real and imaginary parts
12	XLEFT	F10.5	X−coordinate (non−dimensionalized by the input plane outer duct radius) of left end of sideline measurement line. (has to be in the computational domain).
	XRIGHT	F10.5	X−coordinate (non−dimensionalized by the input plane outer duct radius) of right end of sideline measurement line.

12	RSIDE	F10.5	Distance of the measurement line from the duct axis. (be sure this is far enough away not to pass into the standard element domain)
13	HDR(I)	14A4	If another case is being run, this card is setup like Card 1. Otherwise place the word STOP as the first four characters on this line to end execution.

7.4.2 Sample Input

This sample Eversman Radiation module input file comes from the aft radiation code's "TFaNS1.5/aftrad.v4.0/testcases/tst.src" subdirectory. This test case contains contains no acoustic treatment and contains only one case. To run multiple cases, the word stop at the bottom would be replaced by the title for the next case. All other parameters would then be input. When the desired number of cases were input, then a STOP would be placed as the last line in the file on the first four columns of the line.

```
Single case Run (9,2) mode
         1  17.28432         2    9    5
    1    9    1    5     -10.0      10.0
     0.000     0.000     0.000     0.000      1.00      0.00
     0.000     0.000     0.000     0.000
   0
   1
    0.3028 1116.4623  .0023766
     -1.25   9.72327
      -1.0       6.0       4.0
         0       0.8       0.0
STOP
```

7.4.3 Output Files

The Eversman Aft Radiation Code, “aftrad” or “aftrad3d”, outputs the following files:

Output File	**Output File Name**	**When Created**	**What is in it?**
General Output	AFTRAD.OUT	Always	Mode eigenvalues and eigenfunctions (mode shapes), if NPOS > 0. User input Certain mesh parameters Reflected and transmitted modal amplitudes Partial solution vector
Far Field Directivity File	aftdirect.input	Always	Non−dimensional directivities for the circumferential mode order, *m*, given the mode amplitudes, ZAI, input.
Postscript plotting file	AFTRAD.PS	Always	Postscript Contour Plots and directivity Plots for each mode normalized to 100dB
Acoustic Pressure Output formatted for use by other contour plotting codes.	AFCONT.DAT AFCONT2.DAT	when NPOST = 2	Acoustic pressure plotting file for contour plotting (with modifications) on alternative plotting software (e.g. PLOT3D, TECPLOT)
Temporary work files	fort.3 fort.4 ATTEN1.DAT ATTEN2.DAT ATTEN3.DAT ATTEN4.DAT ATTEN5.DAT Plus temporary files 15, 16	Always	*For aftrad:* these files are output to user’s machine. Files 15 and 16 are automatically erased after the successful completion of a code calculation. *For aftrad10:* these files are output to /tmp subdirectory.

There are two options on the manner in which the acoustic pressure contour plot data is calculated:

- NPOST = 1: Only the following postcript oriented postprocessing is done.

  In this version the acoustic pressure is evaluated at each finite element node. This requires the calculation of the mean flow velocity at these nodes and the calculation of the derivative of the acoustic potential at these nodes. The derivatives required for the mean flow velocity and the acoustic pressure are not unique at a given node when calculated from the different elements that share that node. An averaging technique based on the calculation of the derivatives at the node in all elements common to the node was used. A plotting routine

compatible with the nodal description of the pressure field is part of the code. Even with apparently smooth solutions for acoustic potential, the non−uniqueness of the derivatives at nodes may cause pressure contours which are not smooth. This is reduced if the mesh is made more dense, but this increase in mesh density is not generally seen to substantially improve the acoustic potential solution. the pressure in the outer region of infinite elements seems to be much less degraded when pressure is computed from potential.

Plots available are:

1. Zoomed acoustic potential contours for standard elements.
2. Acoustic potential full grid including infinite elements.
3. Acoustic pressure full grid including infinite elements.
4. Cartesian plot of spl versus angle from the axis at specified radius from specified center.
5. Cartesian plot of acoustic pressure versus angle from the axis at specified radius from specified center.
6. Polar directivity at specified radius relative to specified center.
7. Sideline spl directivity on a line parallel to the duct axis and with specified end points.
8. Sideline acoustic pressure directivity on a line parallel to the duct axis and with specified end points.

- NPOST = 2: Outputs same file as NPOST = 1, plus two files for plotting contour curves on an alternative plotting routine.

  This version retains all of the postcript postprocessing above.

  This version produces data for plotting of contour curves on software such as TECPLOT.

  The acoustic pressure is in this version the acoustic pressure is evaluated on a 2 x 2 grid of gauss points in each rectangular element and on a grid of 4 Gauss points in each triangular element. In infinite elements evaluation is on a grid of 25 x 2 points in each element (the code can be easily modified to change this, but this seems to be sufficient). The radial extent of the resulting SPL contour plots can also be easily modified in the code. This produces unique values of the acoustic pressure at every plottings point. The plotting points are arranged in an unstructured grid and therefore in TECPLOT the triangulation option must be used. This requires an additional boundary zone describing the baffle, nacelle, and centerbody in a separate file. TECPLOT files are named ”AFTCONT.DAT” (contour plotting points) and ”AFTCONT2.DAT” (boundary plotting points).

7.5 RADIATION MODULE MODIFIED FOR TFaNS

This version of the radiation Module was modified by Pratt & Whitney to run with TFaNS. Changes to the original code include:

- Capability to run multiple modes and harmonics with unit (m, μ) mode input.
- Dimensional input format based on standard geometry and performance parameters.
- An Acoustic Properties File is output for use by CUP3D.

The system is designed so that it, in effect, reruns each (m, μ) mode one at a time. Note that multiple harmonics of BPF are run with the same mesh. Thus, a user generated mesh must be capable of being accurate for the highest BPF harmonic required.

Note:

- For this case, modes should not be calculated in the mesh generator since they will be ignored by this version of the acoustic radiation calculation.
- The multiple case capability for this version of the radiation module will not run correctly and thus should not be used.

7.5.1 Input Format

Input data files for the TFaNS version of the aft radiation code, "aftrad3d" or "aftrad3d10", are shown below:

Input File	Source
AFTRAD.INP	User Generated input file (see below)
AFTMESH.DAT	Mesh "restart" file created by "aftmesh" (See Section 7.2.2)
AFTFLOW.DAT	Potential flow "restart" file created by "aftflow" or "aftflow10" (See Section 7.3.2)

"aftrad3d" is run if temporary files can be placed on the user's computer. "aftrad3d10" has worked on Sun SPARC workstations at Pratt & Whitney where this code will place all temporary files in the "/tmp" subdirectory.

The input data for the user generated input file, "AFTRAD.INP", has been structured into cards. Each card of data begins on a new line. The input file contains a mixture of free format and fixed format information. The file format is given below:

Line	Variable	Format	Description
1	HDR(I)	14A4	Alphanumeric Title (only the first 56 characters will be read)
2	DUM	A80	Dummy Card used to identify items in card below
3	NSYM	Free format	= 0, Two Dimensional duct =1, circular or annular duct
	NIMP	Free format	= 0, acoustic liner is given by specifying admittances = 1, acoustic liner is given by specifying impedances

4	DUM	A80	Dummy Card used to identify items in card below
5	NHT	Free format	Number of harmonics being predicted (be sure mesh is fine enough to resolve the required frequencies)
	NBLADE	Free format	Number of rotor blades
	NVANE	Free format	Number of stator vanes (creates m = n*NBLADE−k*NVANE per Ref. 15)
6	DUM	A80	Dummy Card used to identify items in card below
7	DINPT	Free format	Duct Diameter at the input plane (inches)
	DFAN	Free format	Duct diameter at Fan Leading Edge Tip Location (inches) (All length dimensions are non−dimensionalized by this in the output files: "aftrad", "aftdirect.input")
	N1C	Free format	Corrected fan speed (rpm)
8	DUM	A80	Dummy Card used to identify items in card below
9	VMACHI	Free format	Mass Averaged compressible Mach number, Stator t.e. (positive for aft flow and based on local sound speed)
	TAMB	Free Format	Far field static temperature (^{o}R)
	PAMB	Free format	Far field static pressure (psf)
10	DUM	A80	Dummy Card used to identify items in card below
11	XSHIFT	Free format	Axial shift of the origin non−dimensionalized by the input plane outer duct radius. Positive value of XSHIFT means shift to the left, i.e. shift towards the nozzle (Use the opposite sign as in the mesh generation routine to get back to the original origin) This parameter determines where the origin of the measurement arc will be placed. *Note:* It is important to assure that the shift, XSHIFT, and arc (arc radius = RM) are not so large that some of it is outside the grid. If the radius is too large, it will be detected and the maximum permissible radius will be used. Similarly, be sure that the measurement radius is not so small that the arc is in the conventional element region. Post processing assumes the directivity is to be obtained in the wave envelope region.
	RM	Free format	Measurement arc radius non−dimensionalized by the input plane duct radius (see note above).
	CUTOFF	Free format	Smallest cutoff ratio for an (m, μ) mode where the code will perform a radiation calculation (not presently used)
12	PRINT1	I5	(Not Used) $\neq$ 0, Beginning row and column in stiffness matrix printed = 0, Beginning row and column in stiffness matrix not printed
	PRINT2	I5	(Not Used) $\neq$ 0, Final row and column in stiffness matrix printed = 0, Final row and column in stiffness matrix not printed

12	NPLOT	I5	(Not Used) > 0, level curves for the solution vector plotted = 0, plotting routine bypassed
	NCONT	I5	Number of contours to be plotted (Postscript plots only)
	CMAXO	F10.5	Value of maximum contour level (Postscript plots only)
	CMINO	F10.5	Value of minimum contour level (Postscript plots only)
13	NLINO	I5	Number of lined elements on the duct outer surface, see Figure 15. (if NLINO =0 there is no lining and ZADMO need not be input)
	MBEGO	I5	Element number (counted along nozzle outer surface from the input plane) on which the lining begins, see Figure 15.
	NLINI	I5	Number of lined elements on the duct inner surface, see Figure 15. (if NLINI =0 there is no lining and ZADMI need not be input)
	MBEGI	I5	Element number (counted along nozzle inner surface from the input plane) on which the lining begins, see Figure 15.
14	ZADMO(I,J)	6F10.5	Input only if NLINO > 0; This parameter is specified at the frequency being run and is non−dimensionalized by the local density x acoustic speed. I = 1, NLINO, J = 1,3; If NIMP = 1, input admittances in each treated node of an element on the duct outer surface (complex: real and imaginary parts, one element per card) If NIMP = 2, input impedances in each treated node of an element on the duct outer surface (complex: real and imaginary parts, one element per card)
15	ZADMI(I,J)	6F10.5	Input only if NLINI > 0; This parameter is specified at the frequency being run and is non−dimensionalized by the local density x acoustic speed. I = 1, NLINI, J = 1,3; If NIMP = 1, input admittances in each treated node of an element on the duct inner surface (complex: real and imaginary parts, one element per card) If NIMP = 2, input impedances in each treated node of an element on the duct inner surface (complex: real and imaginary parts, one element per card)
16	NPOST	I5	= 1, Acoustic pressures for contour plotting are calculated at the nodes and the postscript plotting routines are used for pressure contour plotting. = 2, Acoustic pressures for contour plotting are calculated at the Gauss points in the elements and a data file for a suitable alternative contour plotter (e.g. TECPLOT) is produced.

17	NBAFL	I10	= 0, The baffle admittance option is not used = 1, The baffle admittance option is used
	ZAB	2F10.5	Admittance on the baffle used to produce absorption non−dimensionalized by far−field density x acoustic speed, real and imaginary parts
18	SLON	F10.5	< 1.0 No Sideline Plotting ≥ 1.0 Plot Sideline
	XLEFT	F10.5	X coordinate (non−dimensionalized by the input plane radius) of left end (aft−most point) of sideline measurement line. (has to be in the computational domain)
	XRIGHT	F10.5	X coordinate (non−dimensional) of right end of sideline measurement line.
	RSIDE	F10.5	Distance of the measurement line from the duct axis. (be sure this is far enough away not to pass into the standard element domain)
18	HDR(I)	14A4	Place the word “STOP” as the first four characters on the line

7.5.2 Sample Input

This sample TFaNS Radiation module input file comes from the aft radiation code’s “TFaNS1.5/aftrad.v4.0/testcases/tst.aftrad3d” subdirectory. This test case contains contains no acoustic treatment and contains only one case. Multiple cases should not be run with this code.

```
Sample test case
 NSYM                    NIMP
 1                        1
NHT            NBLADE                  NVANE
3                18                     45
DINPT          DARRAY                  N1C
22.62614       22.000                  5424.
MX             TAMB                    PAMB
0.3028         518.7                  2116.
XSHIFT         RM         CUTOFF
-1.25            9.72327   0.9
    1    9    1   10      -10.0       10.0
   0
   1
         0       0.8        0.0
      0.00      -1.0        6.0        4.0
STOP
```

7.5.3 Output Files

The TFaNS version of the Aft Radiation Code, “aftrad3d” or “aftrad3d10”, outputs the following files:

Output File	**Output File Name**	**When Created**	**What is in it?**
General Output	AFTRAD.OUT	Always	Modes being calculated and mode eigenvalues and eigenfunctions (mode shapes) User input Certain mesh parameters Reflected and transmitted modal amplitudes Partial solution vector
Aft Radiation Acoustic Properties File (for CUP3D)	aftrad	Always	Header cards Scattering coefficients Far−field directivities
Far Field Directivity File (unit input)	aftdirect.input	Always	Non−dimensional directivities for each (m, μ) mode given unit input
Postscript plotting file	AFTRAD.PS	Always	Contour Plots and directivity Plots for each mode normalized to 100dB.
Acoustic Pressure Output formatted for use by other contour plotting codes.	AFCONT.DAT AFCONT2.DAT	when NPOST = 2	Acoustic pressure plotting file for contour plotting (with modifications) on alternative plotting software (e.g. PLOT3D, TECPLOT). May not work for the multiple modes run here.
Temporary work files	fort.3 fort.4 ATTEN1.DAT ATTEN2.DAT ATTEN3.DAT ATTEN4.DAT ATTEN5.DAT Plus temporary files 15,16	Always	*For aftrad3d:* These files are output to user’s machine. Files 15 and 16 are automatically erased after the successful completion of a code calculation. *For aftrad3d10:* these files are output to /tmp subdirectory.

7.6 RUNNING THE SYSTEM

7.6.1 Mesh Generation

Input File	Source
AFTPRE.INP	User Generated input file (see Section 7.2.1) Assumes the nozzle and centerbody surfaces need to be spline fitted. This file is used by Option 1 (see below)
AFTMESH.INP	User Generated input file (see Section 7.2.1) Assumes the user can input the finite element inlet and centerbody three node line elements (surface node locations) for Regions I & II. This file is also generated if option 1 of 'aftmesh' is run. This file is used by Option 2 (see below)

To run the code:

1. Create one of the input files shown above.

2. Bring up a command tool in the subdirectory where this file resides.

3. Make sure the "aftmesh" executable is accessible from the "TFaNS1.5/bin" subdirectory.

4. Type the following command:

   aftmesh

5. The code will then ask:

   WHAT OPTION DO YOU WANT TO RUN, 1 OR 2 ?

   If you are using the file AFTPRE.INP, type 1.
   If you are using the file AFTMESH.INP, type 2.

7.6.2 Potential Flow

Input File	Source
AFTFLOW.INP	User Generated input file (see Section 7.3.1)
AFTMESH.DAT	Mesh "restart" file created by "aftmesh" (See Section 7.2.2)

To run the code:

1. Create the input files shown above.

2. Bring up a command tool in the subdirectory where these files reside.

3. Make sure either the "aftflow" or "aftflow10" executables are accessible from the "TFaNS1.5/bin" subdirectory

4. If running "aftflow", type the following command:

   aftflow &

   If running "aftflow10", type the following command:

   aftflow10 &

   The "&" permits the code to be run in background. If it is left off the code will be run in the foreground.

7.6.3 Eversman Radiation

Input File	Source
AFTRAD.INP	User Generated input file (see Section 7.4.1)
AFTMESH.DAT	Mesh "restart" file created by "aftmesh" (See Section 7.2.2)
AFTFLOW.DAT	Potential flow "restart" file created by "aftflow" or "aftflow10" (See Section 7.3.2)

To run the code:

1. Create the input files shown above.

2. Bring up a command tool in the subdirectory where these files reside.

3. Make sure either the "aftrad" or "aftrad10" executables are accessible from the "TFaNS1.5/bin" subdirectory

4. If running "aftrad", type the following command:

   aftrad

   If running "aftrad10", type the following command:

   aftrad10

5. Answer the following questions:

   ORDER OF THE INFINITE ELEMENTS MULTIPOLE?
   10
   ORDER OF INTEGRATION IN INFINITE ELEMENTS ?
   12

Notes on step 5, Console Input:

You will be asked to specify the order of the multipole represented by the infinite element interpolation. the number of nodes in an infinite element is three times the multipole order. Choices for multipole order are presently 8, 9, 10.

W. Eversman has performed tests with 8th, 9th, and 10th order multipoles (24, 27, and 30 pressure nodes) with evidence of improving performance with increased multipole order.

You will also be asked to specify the integration points in the infinite elements in the radial direction ("$\xi-$direction"). The number of integration points in the spherical direction ("$\eta-$direction") is always 3.

For any choice of pressure nodes the choices for integration points is 9, 10, 12, 16:

The choice of 16 is probably more than is needed and is thus, not checked out.

The following options seem to work reasonably well:

Multipole order 8−−24 pressure nodes−−9 integration points.
Multipole order 9−−27 pressure nodes−−10 integration points.
Multipole order 10−−30 pressure nodes−−12 integration points.

Testing may show that these can be reduced.

W. Eversman's recommended general purpose choice presently is multipole order 10 and 12 integration points.

In general, use of infinite elements allows a smaller standard element mesh, and improved accuracy by reducing reflections from the boundary between the standard elements and the outer region.

7.6.4 TFaNS Radiation

Input File	Source
AFTRAD.INP	User Generated input file (see Section 7.5.1)
AFTMESH.DAT	Mesh “restart” file created by “aftmesh” (See Section 7.2.2)
AFTFLOW.DAT	Potential flow “restart” file created by “aftflow” or “aftflow10” (See Section 7.3.2)

To run the code:

1. Create the input files shown above.

2. Bring up a command tool in the subdirectory where these files reside.

3. Make sure either the “aftrad3d” or “aftrad3d10” executables are accessible from the “TFaNS1.5/bin” subdirectory.

4. If running “aftrad3d”, type the following command:

   aftrad3d

   If running “aftrad3d10”, type the following command:

   aftrad3d10

5. Answer the following questions (see previous section for notes on this console input):

```
ORDER OF THE INFINITE ELEMENTS MULTIPOLE?
10
 ORDER OF INTEGRATION IN INFINITE ELEMENTS ?
12
```

8. AWAKEN CFD/MEASURED WAKE POSTPROCESSOR

8.1 GENERAL ORGANIZATION OF AWAKEN

The purpose of the AWAKEN CFD/Measured Wake Postprocessor is to convert a standard SOURCE3D input file into one which contains upwash wake harmonic amplitudes from an outside source (e.g. CFD or Measured wakes). To do this calculation, AWAKEN starts with CFD predicted or measured velocities and calculates upwash wake harmonic amplitudes for the number of harmonics specified by the original SOURCE3D input file. This original SOURCE3D input file is then modified to include the upwash wake harmonic amplitudes calculated by AWAKEN for use by SOURCE3D. None of the performance information in the SOURCE3D file is changed from their original values (i.e. no CFD or measured performance is presently used by SOURCE3D). Only the wake harmonic amplitudes are added.

AWAKEN handles wake radial phasing by determining the centerline of the hub wake and then phasing the other radii relative to that hub wake centerline. This circumferential location is what SOURCE3D considers to be zero circumferential phase in its calculations. This hub wake centerline location is either known (not likely) or determined using AWAKEN methods. If information is given radially along a constant axial plane, the AWAKEN code will adjust the upwash wake harmonic amplitudes for the phase shift from the contant axial plane to the stator leading edge. However, it assumes that the magnitude of the upwash wake harmonic amplitudes do not change. The specifics of this theory are not discussed here.

8.2 INPUT FILE STRUCTURE

Two files are required to run the AWAKEN code:

- User Generated Input File (see Section 8.2.1)
- Acoustic Wake/Turbulence File (see Section 8.2.2)

The User Generated Input File consists of a standard SOURCE3D rotor wake/stator interaction code input file (see Section 5.2) with some additional input parameters added in order to calculate the upwash wake harmonic amplitudes (see below).

The Acoustic Wake/Turbulence File is generated by either a CFD code or postprocessor or during an engine or rig test program. It contains CFD or measured velocities (three components), turbulent kinetic energy and dissipation rate, Reynolds stresses, and integral length scale where the information was predicted or measured over one or more blade passages and radii. The information is given along a plane (either a contant axial plane or along the stator leading edge). It also contains total temperatures and pressures versus radius at a given axial and radial locations which may not correspond to where the velocity and turbulence was predicted or measured.

In this section, “measurements” refer to information in the Acoustic Wake/Turbulence file; “predictions” refer to information from the AWAKEN User Generated Input file.

8.2.1 User Generated Input File

The AWAKEN input file takes on the exact same form as a SOURCE3D input file (see Section 5.2) with the following additions:

IWAKM – Indicates whether PHIPR is included in the Acoustic Wake/Turbulence file (see next section for the definition of PHIPR)

= 0 Hub Wake Centerline is the location of (i, j) = (1, 1) (default)
where i = radial direction, j = circumferential direction (see Figure 20)
= 1 PHIPR is supplied in the Acoustic Wake/Turbulence File
= 2 PHIPR will be calculated by AWAKEN

If IWAKM = 2 then input RADPHI1.

RADPHI1 – Radius (inches) where the circumferential location of the center of a wake, φ_1, will be calculated. If this does not correspond to a wake measurement location, the nearest radial location will be chosen by the code. A location near 50% span is normally a good radius to specify, as engines tend to have well behaved wakes at this radius. (default = 0.0)

IMEAS – Determines where the wake/turbulence information is given.

= 0 Wake/turbulence information is given at the axial location, $X_{PR_{TIP}}$ (default)
= 1 Wake/turbulence information is along the stator l.e. For this case $X_{PR_{TIP}}$ denotes the axial location of the stator leading edge at the tip but is not used in the calculations.

The definition of $X_{PR_{TIP}}$ is found in the next section which discusses the Acoustic Wake/Turbulence File.

If IMEAS = 0 then input IACLMR.

IACLMR – Determines how the wake phasing is treated as the wake moves from a constant axial location to the stator leading edge.

= 1 Use predicted BETA2D, ACLS values from User Generated Input to calculate the average relative air angle to determine the phase shift from the measurement location to the stator l.e. (default)
= 2 Use measured ACLS values calculated from the Acoustic Wake/Turbulence File (at axial location, $X_{PR_{TIP}}$) to phase shift the wake from the measurement location to the stator l.e. When extrapolating these values beyond the measured radii range, the average of the predicted ACLS and BETA2D values are used and adjusted to match the measured air angle at the last measurement location.

ACLS = Relative air angle relative to the circumferential direction at:
• Stator leading edge in the User Generated Input File,
• $X_{PR_{TIP}}$ in the Acoustic Wake/Turbulence File.
BETA2D = Relative air angle at the rotor trailing edge relative to the circumferential direction.

WAKEINPT – Name of the file containing the Acoustic Wake/Turbulence File. The name must be surrounded by single quotes.

- Measurements can be at different axial locations for each radius
- Measurements are along constant radial lines and constant circumferential lines
- Circumferential angle between mesh points is evenly spaced

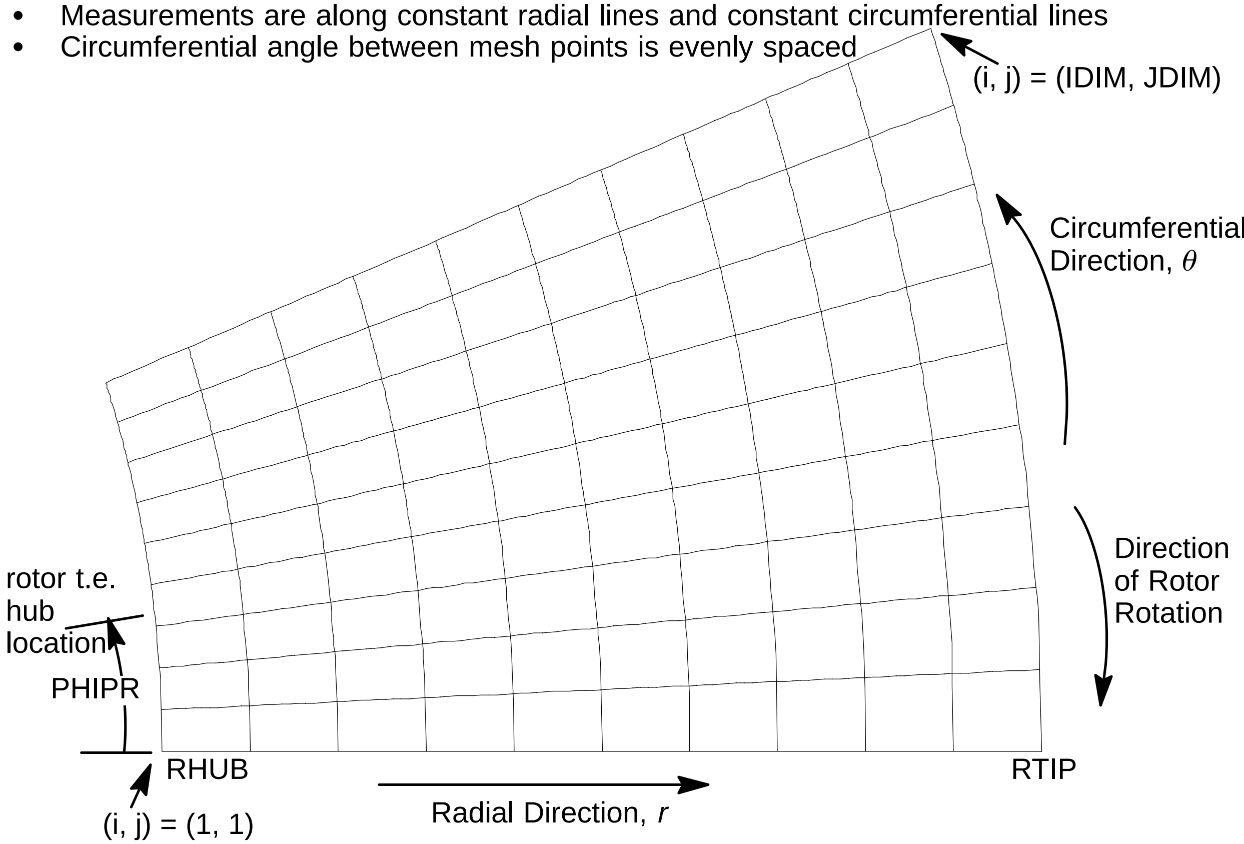


Figure 20: Sample mesh over one blade passage with varying axial location from radius to radius for the velocities and turbulence in a Acoustic Wake/Turbulence File.

8.2.2 Acoustic Wake/Turbulence File

An Acoustic Wake/Turbulence File can contain CFD or measured velocities (three components), turbulent kinetic energies and dissipation rates, Reynolds stresses, integral length scale, and total temperatures and pressures along planes where the information was predicted or measured over one or more blade passages.

This input file is split into two parts:

- Velocity and turbulence information
- Total pressure and total temperature information

It is assumed that these two sets of ”measurements” may be at two different locations in the duct in order to permit these measured data and CFD information to be stored in the same type of file. Sections 8.2.2.1 and 8.2.2.2 define the data which is stored in this file. Section 8.2.2.3 discusses the Acoustic Wake/Turbulence File format.

8.2.2.1 Velocity and Turbulence Information

Information is on a (r, θ) surface with the axial coordinate, Z defined as a function of radius (see Figure 20). This definition permits surfaces to be defined at an axial location or on an arbitrary surface (e.g. at an FEGV leading edge). The origin of the axial coordinate, Z, is defined at the rotor tip trailing edge where Z is positive in the downstream direction.

Also, the present AWAKEN code requires velocity and turbulence information to be stored using a constant circumferential distance between measurement points. It also requires that the data be stored with positive circumferential direction in the direction opposite rotor rotation (consistent with SOURCE3D and V072). Also, the data are stored along radial lines starting at the inner most radius and going to the outer most radius. This permits a Fourier transform to be calculated which incorporates the wake phase lag directly into the result.

The following velocity and turbulence information are stored in this file:

IWAKTYPE = 1 CFD Wake Predictions are in this File
= 2 Measured Wake Data are in this File

DATA_N1 = rotor rotational speed (rpm)
Note: If DATA_N1 is input as a negative number, it will always be converted to a positive number in order to calculate velocity triangles consistently.

XPRTIP = Axial distance from the rotor trailing edge tip to the velocity measurement plane tip location (inches)

RHUB = inner duct radius at the velocity measurement plane (inches)
RTIP = outer duct radius at the velocity measurement plane (inches)

NPASSAGE = Number of measurement points in one blade passage.
This number includes the two endpoints. To Fourier transform over many passages, set NPASSAGE = Number of measurement points in multiple blade passages including the beginning and end points.

PHIPR = Angular distance from the first circumferential data point in the file, (i, j) = (1, 1), to nearest rotor trailing edge at the hub (radians). PHIPR is positive in the direction opposite rotor rotation relative to the first circumferential data point in the file.

IDIM = number of radial measurement points for velocities and turbulence
JDIM = number of circumferential measurement points for velocities and turbulence

Z = axial coordinates for velocities and turbulence (inches)
X = x−coordinates for velocities and turbulence (inches)
Y = y−coordinates for velocities and turbulence (inches)
Note: $r = \sqrt{X^2 + Y^2},\ \theta = \tan^{-1}\left(\frac{Y}{X}\right)$

CX = axial component of velocity (ft/sec)
CU = circumferential component of velocity in the stationary reference frame (ft/sec)
CR = radial component of velocity (ft/sec)
Note: If CU is input as a negative number, it will always be converted to a positive number for the purposes of calculating the total absolute velocity. CR is positive towards the duct tip. CX is positive downstream.

TKE = Turbulent kinetic energy (ft^2/sec^2)

EPS = turbulent dissipation rate (ft**2/sec**3)
CPXCPX = x−x Reynolds stress (ft**2/sec**2)
CPUCPU = u−u Reynolds stress (ft**2/sec**2)
CPRCPR = r−r Reynolds stress (ft**2/sec**2)
CPXCPU = x−u Reynolds stress (ft**2/sec**2)
CPXCPR = x−r Reynolds stress (ft**2/sec**2)
CPUCPR = u−r Reynolds stress (ft**2/sec**2)
SCALE = integral length scale (in)

where: r = radial direction, u = circumferential direction, x = axial direction.

8.2.2.2 Total Pressure and Total Temperature Information

Circumferentially averaged total pressures/temperatures are needed for the broadband noise code. These data are normally available from a test program or can be calculated from CFD code output. It is assumed that this information may be ”measured” at a different axial location than the wake/turbulence data.

The following pressure and temperature information are stored in this file:

ZTIP2 = axial distance from the rotor trailing edge tip to the PT2,TT2 measurement plane tip location (inches)

RHUB2 = inner duct radius along the PT2,TT2 measurement plane (inches)
RTIP2 = outer duct radius along the PT2,TT2 measurement plane (inches)

IDIM2 = number of radii where PT2, TT2 were measured

R2 = radial coordinates where PT2, TT2 were measured (inches)

Z2 = axial coordinates relative to the rotor tip t.e. corresponding to the radial coordinates where PT2, TT2 were measured (inches)

PT2 = circumferentially averaged total pressure at each measurement location (psfa)
TT2 = circumferentially averaged total temperature at each measurement location (deg. R)

Note that IF IWAKTYPE = 1 (CFD PREDICTIONS)
ZTIP2 = XPRTIP
RHUB2 = RHUB
RTIP2 = RTIP
IDIM2 = IDIM

8.2.2.3 Acoustic Wake/Turbulence File Format

This file format is intended to be common between the TFaNS Tone Fan Noise Design/Prediction System and the BFaNS Broadband Fan Noise Design/Prediction System. Future changes to BFaNS may require changes to the turbulence levels in this file. Information through the steady velocities, however, must continue to be in the format shown to be compatible with AWAKEN.

The file format for the parameters given in the previous sections is shown below:

```
C
C      OPEN WAKE FILE
C
       OPEN(FILE = WAKEINPT, UNIT = IREAD, STATUS='OLD')
C
       READ(IREAD,*) IWAKTYPE
       READ(IREAD,*) DATA_N1,XPRTIP,RHUB,RTIP,NPASSAGE,PHIPR
C
       READ(IREAD,*) IDIM,JDIM
       READ(IREAD,*) (Z(I),I=1,IDIM)
       READ(IREAD,*) ((X(I,J),I=1,IDIM),J=1,JDIM)
       READ(IREAD,*) ((Y(I,J),I=1,IDIM),J=1,JDIM)
C
       READ(IREAD,*) ICX,ICU,ICR,ITKE,IEPS,ICPXCPX,ICPUCPU,
  &                  ICPRCPR,ICPXCPU,ICPXCPR,ICPUCPR,ISCALE
      IF (ICX .EQ. 1) THEN
         READ(IREAD,*) ((CX(I,J),I=1,IDIM),J=1,JDIM)
      ENDIF
      IF (ICU .EQ. 1) THEN
         READ(IREAD,*) ((CU(I,J),I=1,IDIM),J=1,JDIM)
      ENDIF
      IF (ICR .EQ. 1) THEN
         READ(IREAD,*) ((CR(I,J),I=1,IDIM),J=1,JDIM)
      ENDIF
      IF (ITKE .EQ. 1) THEN
         READ(IREAD,*) ((TKE(I,J),I=1,IDIM),J=1,JDIM)
      ENDIF
         IF (IEPS .EQ. 1) THEN
         READ(IREAD,*) ((EPS(I,J),I=1,IDIM),J=1,JDIM)
      ENDIF
      IF (ICPXCPX .EQ. 1) THEN
         READ(IREAD,*) ((CPXCPX(I,J),I=1,IDIM),J=1,JDIM)
      ENDIF
      IF (ICPUCPU .EQ. 1) THEN
         READ(IREAD,*) ((CPUCPU(I,J),I=1,IDIM),J=1,JDIM)
      ENDIF
      IF (ICPRCPR .EQ. 1) THEN
         READ(IREAD,*) ((CPRCPR(I,J),I=1,IDIM),J=1,JDIM)
      ENDIF
      IF (ICPXCPU .EQ. 1) THEN
         READ(IREAD,*) ((CPXCPU(I,J),I=1,IDIM),J=1,JDIM)
      ENDIF
```

```
      IF (ICPXCPR .EQ. 1) THEN
         READ(IREAD,*) ((CPXCPR(I,J),I=1,IDIM),J=1,JDIM)
      ENDIF
      IF (ICPUCPR .EQ. 1) THEN
         READ(IREAD,*) ((CPUCPR(I,J),I=1,IDIM),J=1,JDIM)
      ENDIF
      IF (ISCALE .EQ. 1) THEN
         READ(IREAD,*) (SCALE(I),I=1,IDIM)
      ENDIF
C
      READ(IREAD,*) ZTIP2,RHUB2,RTIP2
C
      READ(IREAD,*) IDIM2
C
      READ(IREAD,*) (R2(I),I=1,IDIM2)
      READ(IREAD,*) (Z2(I),I=1,IDIM2)
C
      READ(IREAD,*) (PT2(I),I=1,IDIM2)
      READ(IREAD,*) (TT2(I),I=1,IDIM2)
C
C     CLOSE WAKE FILE
C
      CLOSE(IREAD)
```

8.3 OUTPUT FILE STRUCTURE

The output file from this code is a SOURCE3D input file (see Section 5.) with IWAKE set equal to zero and wake harmonic amplitudes calculated by AWAKEN added to the SOURCE3D file.

8.4 RUNNING THE CODE

To run AWAKEN:

1. Insure that the awaken executable located in the “TFaNS1.5/bin” subdirectory has been sourced.

2. Bring up a command tool in the subdirectory where the User Generated Input File and the Acoustic Wake/Turbulence File are located.

3. Type:

   awaken<input_filename>output_filename

   where:

   input_filename is the User Generated Input File explained above.

   output_filename is the SOURCE3D file name (chosen by the user) with outside wakes added.

8.5 SAMPLE USER GENERATED INPUT FILE

Sample Input – This example is the input used to make the output in Section 5.6.2 for SOURCE3D. This case is the test case in the "TFaNS1.5/awaken.v1.1/testcases/data.input" subdirectory.

```
Sample Test Case – AWAKEN with measured data input
&INPUT
ISTAGE=1, IPRED=1, ICASE=  1, IPRINT=0,
NDATS= 15, NHT= 3,
IWAKE=1, ISHAPE=3, EPSIL=3.0,
NBLADE= 18, NVANES= 45,
DDUCT= 22.0000,
XROT=  –1.098,      XROT1=  –1.250,      XROT2=   4.020,
XSTAT=   6.592,  XSTAT1=   4.020,   XSTAT2=   8.229,
RSWR= 10.159, RSWS= 10.159,
RADIUS=
       5.3933,  5.4854,  5.6153,  5.9545,  6.4688,  6.9457,
       7.3931,  7.9711,  8.5663,  9.1277,  9.6913, 10.0316,
      10.3636, 10.6870, 11.0000,
BROTOR=
       2.8296,  2.8572,  2.8961,  2.9974,  3.1159,  3.2128,
       3.3037,  3.4174,  3.5371,  3.6493,  3.7566,  3.8180,
       3.8753,  3.9336,  3.9896,
ALPHCHR=
        65.18,  65.15,  65.10,  64.97,  63.97,  62.40,
        60.46,  56.81,  53.00,  49.72,  46.52,  44.39,
        41.79,  38.67,  35.30,
YRD=
       0.0936,  0.1033,  0.1168,  0.1523,  0.1872,  0.1948,
       0.1862,  0.1219,  0.0406, –0.0331, –0.1061, –0.1549,
      –0.2137, –0.2850, –0.3581,
YRLED=
      –0.0144, –0.0159, –0.0180, –0.0235, –0.0416, –0.0641,
      –0.0977, –0.1501, –0.1987, –0.2351, –0.2678, –0.2902,
      –0.3208, –0.3613, –0.4007,
XRLED=
       0.0000,  0.0119,  0.0287,  0.0725,  0.1187,  0.1507,
       0.1708,  0.1628,  0.1444,  0.1207,  0.0913,  0.0646,
       0.0209, –0.0404, –0.1125,
XSPAC=
       5.1441,  5.1304,  5.1112,  5.0689,  5.0290,  4.9968,
       4.9818,  4.9664,  4.9570,  4.9565,  4.9570,  4.9781,
       4.9989,  5.0520,  5.1100,
BSTATR=
       1.6751,  1.6751,  1.6751,  1.6751,  1.6751,  1.6751,
       1.6751,  1.6751,  1.6751,  1.6751,  1.6751,  1.6751,
       1.6751,  1.6751,  1.6751,
ALPHCH=
        48.33,  49.46,  50.73,  53.14,  55.62,  57.32,
        58.63,  60.05,  61.26,  62.18,  62.91,  63.22,
        62.66,  60.27,  54.83,
```

```
YSD=
       0.0000, –0.0260, –0.0574, –0.1231, –0.2007, –0.2604,
      –0.3107, –0.3706, –0.4274, –0.4774, –0.5244, –0.5509,
      –0.5656, –0.5562, –0.5119,
XSD=
       0.0000,  0.0176,  0.0358,  0.0654,  0.0908,  0.1064,
       0.1171,  0.1275,  0.1350,  0.1400,  0.1432,  0.1442,
       0.1410,  0.1279,  0.0936,
N1C=   8749.8,
T01= 518.70, TAMB= 518.70, PAMB=2116.00,
TSI= 492.69, RHOI= 0.0673, MAI= 0.5130,
TSR= 525.87, RHOR= 0.0781, MAR= 0.4469,
TSS= 531.77, RHOS= 0.0803, MAS= 0.3996,
TSE= 539.99, RHOE= 0.0829, MAE= 0.4285,
MRSWR= 0.5592,ALPHASWR=  56.04,
MRSWS= 0.5229,ALPHASWS=  54.91,
MX=
       0.5216, 0.5216, 0.5219, 0.5233, 0.5255, 0.5266,
       0.5260, 0.5229, 0.5172, 0.5103, 0.5015, 0.4958,
       0.4911, 0.4897, 0.4971,
MRABSR=
       0.5471, 0.5495, 0.5532, 0.5638, 0.5789, 0.5937,
       0.6086, 0.6300, 0.6547, 0.6804, 0.7086, 0.7264,
       0.7401, 0.7450, 0.7365,
BETA1D=
        54.02, 53.56, 52.93, 51.37, 49.15, 47.19,
        45.37, 43.05, 40.71, 38.56, 36.44, 35.21,
        34.09, 33.21, 32.83,
BETA2D=
        71.92, 72.32, 72.89, 73.85, 74.44, 73.57,
        71.11, 66.53, 61.98, 58.17, 54.47, 52.12,
        49.20, 45.73, 41.72,
OMEGA=
       0.0471, 0.0425, 0.0361, 0.0213, 0.0162, 0.0159,
       0.0162, 0.0167, 0.0174, 0.0181, 0.0182, 0.0206,
       0.0442, 0.1087, 0.2278,
MRABS=
       0.3180, 0.3391, 0.3665, 0.4248, 0.4882, 0.5277,
       0.5479, 0.5568, 0.5589, 0.5568, 0.5469, 0.5341,
       0.5071, 0.4625, 0.4019,
ACLS=
        56.50, 58.50, 60.62, 63.87, 66.22, 66.47,
        64.94, 61.46, 57.77, 54.38, 50.58, 47.83,
        44.07, 38.79, 30.14,
 WAKEINPT='wakeinpt_LDV_8750_sta2',
IWAKM = 2,IMEAS=1,RADPHI1 = 8.0,
&END
```

9. REFERENCES

1 Topol, D. A. and Eversman, W., "Tone Fan Noise Design/Prediction System, Volume II: User's Manual, TFaNS Vers 1.4," NASA/CR−1999−208883, March 1999.

2 Hanson, D. B., "Mode Trapping in Coupled 2D Cascades − Acoustic and Aerodynamic Results," AIAA−93−4417, October 1993.

3 Topol, D. A., "Tone Fan Noise Design/Prediction System, Volume I: System Description, CUP3D Technical Documentation and Manual for Code Developers," NASA/CR−1999−208882, March 1999.

4 Meyer, H. D., "Source Methodology for Turbofan Noise Prediction (SOURCE3D Technical Documentation)," NASA/CR−1999−208877, March 1999.

5 Roy, I. D., and Eversman, W., and Meyer, H. D.,"Improved Finite Element Modeling of the Turbofan Engine Inlet Radiation Problem," Informal Report to NASA Lewis, April 1993.

6 Roy, I. D., and Eversman, W., "Development of the Turbofan Acoustic Radiation Code: Code Improvements, Acoustic Treatment, and Aft Radiation Including Shear Layer Effects," Informal Report to NASA Lewis, May 1994.

7 Eversman, W., and Okunbor, D., "Development of the Inlet and Aft Fan Duct Acoustic Radiation Codes," Informal Report to NASA Lewis under NASA Grant NASA NAG3 1678, April 1996.

8 Eversman, W., and Okunbor, D., "An Improved Finite Element Formulation for Aft Fan Duct Acoustic Radiation," Informal Report to NASA Lewis under NASA Grant NASA NAG3 1678, June 1997.

9 Roy, I. D., and Eversman, W., "Far−Field Calculations for Turbofan Noise," AIAA Journal, Vol. 39, No. 12, p.p. 2255−2261, December 2001.

10 Topol, D. A., "Tone Fan Noise Design/Prediction System, Volume III: Evaluation of System Codes," NASA/CR−208884, March 1999.

11 Philpot, M. G., "The Attenuation of Forward Arc Fan Tone Noise due to Rotor Blade Blockage Effects," National Gas Turbine Establishment, Report No. N.G.T.E. R−332, August 1974.

12 Topol, D. A., "BBN/PW V072 Rotor Wake/Stator Interaction Code − Technical Documentation and User's Manual," NASA Contract NAS3−25952 Task 10, April 1993.

13 Meyer, H. D. and Envia, E., "Aeroacoustic Analysis of Turbofan Noise Generation," NASA CR−4715, March 1996.

14 Majjigi, R. K., and Gliebe, P. R., "Development of a Rotor Wake/Vortex Model," NASA−CR−174849, June 1984.

15 Tyler, J. M. and Sofrin, T. G., "Axial Flow Compressor Noise Studies," SAE Transactions, 1961.

16 Lieblein, S., Schwenk, F. C., and Broderick, R. L., "Diffusion Factor For Estimating Losses and Limiting Blade Loadings in Axial−Flow−Compressor Blade Elements," NACA RME53D01, June 8, 1955.

APPENDIX I: ORGANIZATION OF TFaNS DIRECTORIES

The purpose of this section is to outline for the TFaNS user and code developer the organization of the TFaNS Subdirectory system. For TFaNS 1.5 the system is shown in Figure 21. The main subdirectory is given by TFaNS followed by the version number. Below this directory are the five code subdirectories. Each one is denoted by the type of code along with a version number. The codes in this system are:

- inlrad.v4.0 – Eversman Inlet Radiation code Version 4.0
- source3d.v2.6 – SOURCE3D Rotor Wake/Stator Interaction Code Version 2.6
- aftrad.v4.0 – Eversman Aft Radiation code Version 4.0
- cup3d.v2.1 – CUP3D Fan Noise Coupling Code Version 2.1
- awaken.v1.1 – AWAKEN CFD/Measured Wake Postprocessor Version 1.1

Under each of these subdirectories are source directories (src), libraries, and test case directories (testcases). Along with each test case is an output subdirectory containing test case output files.

There is also a “bin” subdirectory. This directory is where all code executables are stored for ease of access.

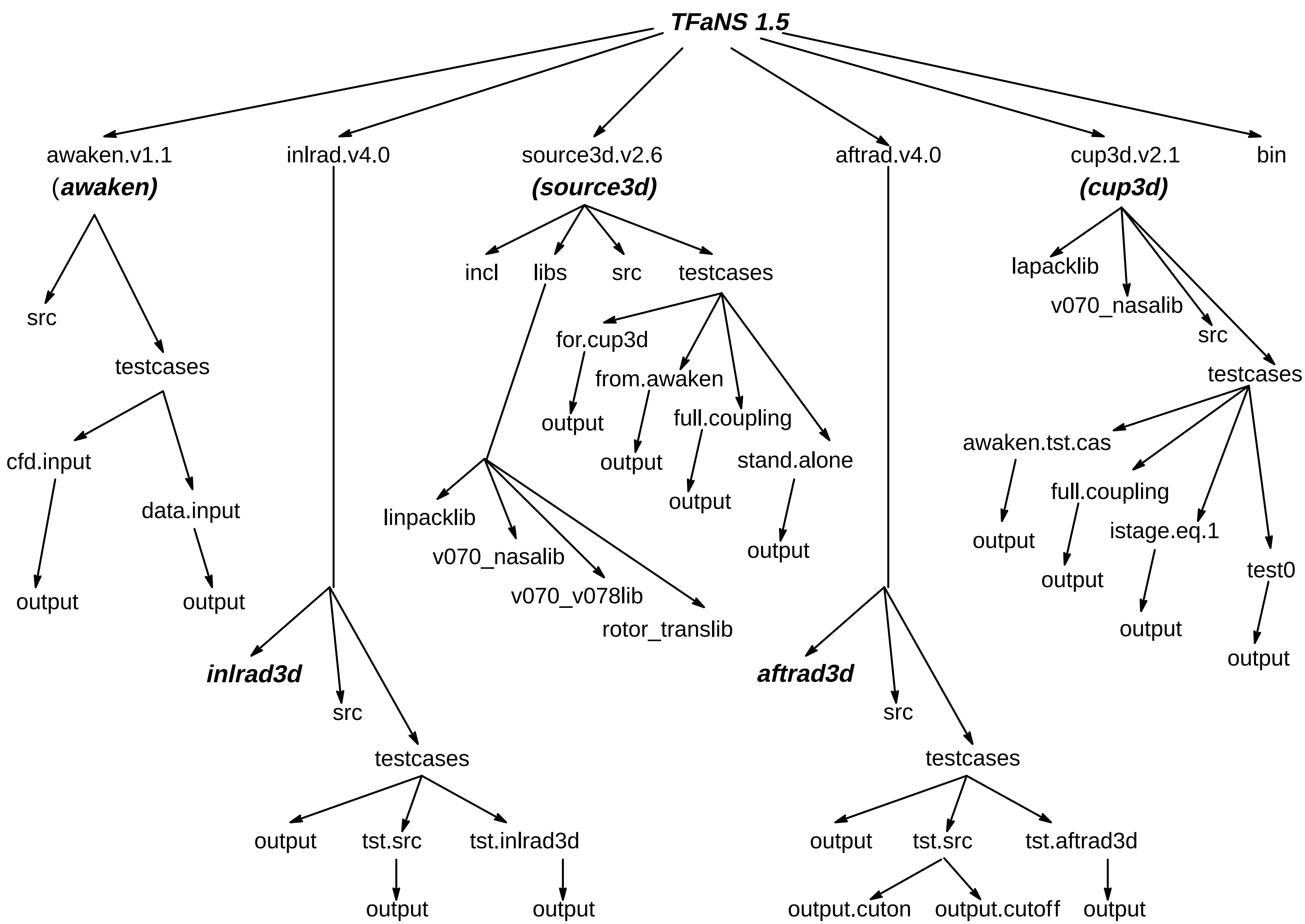


Figure 21: Subdirectory Structure for the Tone FAn Noise design/prediction System (TFaNS)

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (*Leave blank*)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	June 2003	Final Contractor Report

4. TITLE AND SUBTITLE

TFaNS—Tone Fan Noise Design/Prediction System
Users' Manual, TFaNS Version 1.5

5. FUNDING NUMBERS

WBS–22–781–30–09
NAS3–27727, Task Order 13

6. AUTHOR(S)

David A. Topol

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

United Technologies Corporation, Pratt & Whitney
400 Main Street
East Hartford, Connecticut 06108

8. PERFORMING ORGANIZATION REPORT NUMBER

E–13957

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

National Aeronautics and Space Administration
Washington, DC 20546–0001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

NASA CR—2003-212380

11. SUPPLEMENTARY NOTES

Project Manager, Dennis L. Huff, Structures and Acoustics Division, NASA Glenn Research Center, organization code 5940, 216–433–3913.

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Unclassified - Unlimited
Subject Category: 71 Distribution: Nonstandard

Available electronically at http://gltrs.grc.nasa.gov

This publication is available from the NASA Center for AeroSpace Information, 301–621–0390.

12b. DISTRIBUTION CODE

13. ABSTRACT ***(Maximum 200 words)***

TFaNS is the Tone Fan Noise Design/Prediction System developed by Pratt & Whitney under contract to NASA Glenn. The purpose of this system is to predict tone noise emanating from a fan stage including the effects of reflection and transmission by the rotor and stator and by the duct inlet and nozzle. The first version of this design system was developed under a previous NASA contract. Several improvements have been made to TFaNS. This users' manual shows how to run this new system. TFaNS consists of the codes that compute the acoustic properties (reflection and transmission coefficients) of the various elements and writes them to files, CUP3D Fan Noise Coupling Code that reads these files, solves the coupling problem, and outputs the desired noise predictions, and AWAKEN CFD/Measured Wake Postprocessor which reformats CFD wake predictions and/or measured wake data so they can be used by the system. This report provides information on code input and file structure essential for potential users of TFaNS.

14. SUBJECT TERMS

Acoustics; Turbomachinery; Noise; Fan; Acoustic radiation; Wakes; Wake modeling; Rotor/stator interaction

15. NUMBER OF PAGES

140

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	